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FINAL REPORT

ON

INVESTIGATION OF STORAGE SYSTEM DESIGNS AND TECHNIQUES FOR OPTIMIZING ENERGY CONSERVATION IN INTEGRATED UTILITY SYSTEMS

VOLUME II

(APPLICATION OF ENERGY STORAGE TO IUS)

MARCH 10, 1976

(NASA-CR-147592) INVESTIGATION OF STORAGE SYSTEM DESIGNS AND TECHNIQUES FOR OPTIMIZING ENERGY CONSERVATION IN INTEGRATED UTILITY SYSTEMS. VOLUME 2: (APPLICATION OF ENERGY STORAGE TO IUS) Final (Battelle Columbus G3/44 N76-22663 Unclas 26808

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PREFACE

This is the second of a three-volume set comprising the final report on the study entitled "Investigation of Storage System Designs and Techniques for Optimizing Energy Conservation in Integrated Utility Systems". The research program was sponsored by the Urban Systems Project Office at National Aeronautics and Space Administration's Lydon B. Johnson Space Center (NASA-JSC) and was performed by Battelle's Columbus Laboratories (BCL) under Contract No. NAS9-14628. The volumes are entitled

- Volume I - Executive Summary
- Volume II - Application of Energy Storage to IUS
- Volume III - Assessment of Technical and Cost Characteristics for Candidate IUS Energy Storage Devices.

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INTRODUCTION

The applicability of energy storage devices to any energy system obviously depends, to a large extent, on the performance and cost characteristics of the larger basic system. A comparative assessment of energy storage alternatives for application to IUS must, therefore, address the "systems" aspects of the overall installation. This second volume of the three volume series describing the subject study emphasizes these system considerations in addition to describing the overall framework for carrying out the comparative assessment. Included are (1) descriptions of the two no-storage IUS baselines utilized as "yardsticks" for comparison throughout the study, (2) discussions of the assessment criteria and the selection framework employed, (3) a summary of the rationale utilized in selecting water storage as the primary energy storage candidate for near term application to IUS, (4) discussion of the integration aspects of water storage systems, and (5) an assessment of IUS with water storage in alternative climates.

BASELINE DEFINITION

The objective of the Baseline Definition task was to establish a benchmark for comparison of the alternative energy storage concepts as well as to devise a framework for carrying out the assessment and selection tasks. The approach to this task involved the following subtasks:

(1) Conceptualization of IUS baseline systems for use as a yardstick for comparison of energy storage alternatives

(2) Development of an energy supply computer model to assist in comparisons of alternative energy storage schemes

(3) Establishment of reference load profiles based on inputs from NASA-JSC

(4) Establishment of a framework for the comparative assessment including criteria and weighing factors.

Baseline Concepts

A 1000-Unit Apartment and a Village Complex were selected as the target developments to be served by the IUS baselines. These communities had both been examined in detail in previous studies [1,2]* at NASA-JSC and energy demand profiles were available for each. In addition, the selection of these two communities resulted in an indication of the effect of development size on the applicability of energy storage. The 1000-Unit Apartment represents the low end of the size range thought feasible for IUS due to the economics of scale. The Village Complex, on the other hand, has electrical loads which are approximately an order of magnitude higher than the Apartment application. Both communities were originally assumed to be located in a region with climatic conditions similar to Washington, D.C. The effect of alternate climates was later examined for the primary storage candidate utilizing energy demand profiles corresponding to Houston, Texas, and Minneapolis, Minnesota.

* Numbers in brackets indicate references immediately following the last page of text in this volume.

The 1000-Unit Apartment consists of 40 separate buildings which house approximately 2400 people. Four separate building types are included--high rise apartment buildings, low rise (3 story) single apartments and two types of low rise family apartments. Distribution of utility services is by means of a series of trenchs which contain potable water lines, hot water supply and return, chilled water supply and return, and electrical conductors.

The Village Complex is a composite of three identical neighborhoods and a centralized village center which serves as a center of activity for the Village Complex. The village center includes office buildings, retail business establishments, schools, and medium rise apartments. The neighborhoods each contain 713 single family residences and 648 multifamily housing units for a total of 1361 families. Each neighborhood also contains an elementary school.

Figure 1 is a simplified block diagram depicting the energy flow in the IUS baselines. The performance characteristics of the specific equipment comprising the system were drawn, wherever possible, from the results of previous NASA-JSC studies. For example, the prime mover/generator sets for the 1000-Unit Apartment were assumed to be the same Fairbanks-Morse 478 kW diesel units which were utilized in Reference 1. Likewise, the Nordberg 4415 kW diesel generator sets recommended in Reference 2 were used for the Village Complex.

The no-storage IUS supplies all of the electrical requirements of the community being served via diesel generators (i.e., as if there were no tie-in with a regional electricity supply grid). These units are equipped with heat recovery devices and the recovered heat is utilized to supply space heating demands, hot water heating demands, and cooling demands (through absorption chillers). The recovered thermal energy is supplemented by a heat recovery incinerator and, when necessary, by an auxiliary boiler. When the recovered thermal energy is greater than the thermal demand, the excess heat is rejected to a cooling tower. During periods when the cooling demand exceeds the capacity of the absorption chillers, electric chillers are brought on line to satisfy the cooling load.

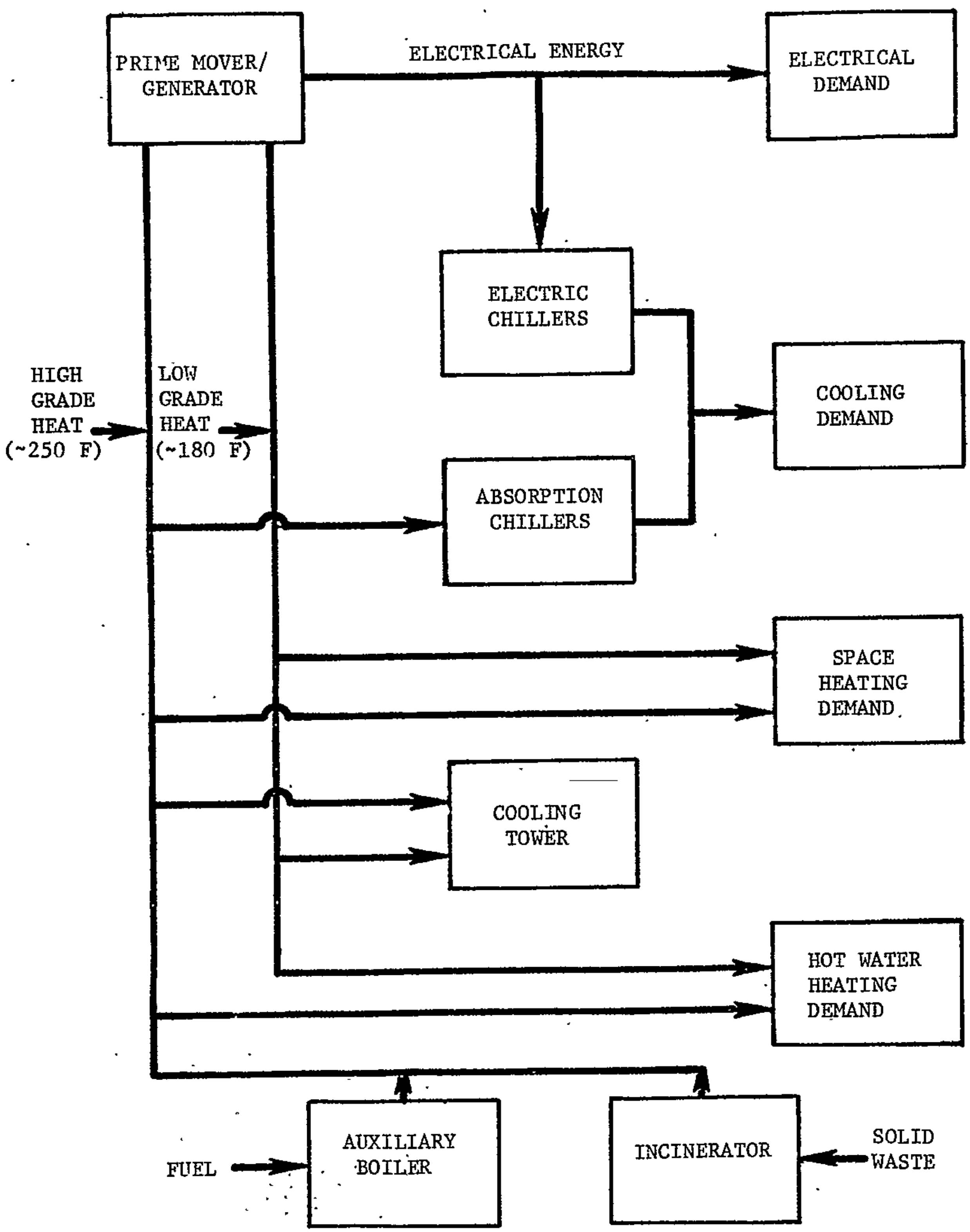

FIGURE 1. BLOCK DIAGRAM OF NO-STORAGE IUS

Table 1 gives details on the sizing and performance characteristics of the equipment utilized in the two IUS baselines. As mentioned earlier, much of the performance information has been drawn from References 1 and 2. The sizing information was based on the results of computer simulations described elsewhere in this report. It has been assumed, for the purposes of this study, that all of the electrical energy required by the baseline communities is generated on-site and that power may be drawn from a conventional utility grid only during emergencies. This assumption results in the necessity of installing electrical generation capacity sufficient to meet the peak electrical demand. In the extreme case, this assumption would also require the installation of additional generators to carry the load when maintenance is being performed on one of the primary generators; standby generators, however, are not included in the Table 1 equipment summary.

IUS Computer Model

A computer model, IUSMOD, was developed to aid in the analysis of energy storage imbedded in the IUS baselines. This program, which is described in more detail in Appendix B, is basically an energy flow simulation. It calculates the fuel required by prime movers and auxiliary boilers to supply the electrical, space heating, space cooling, and water heating requirements of the baseline communities.

Input required by the program includes the hour-by-hour demand profiles for hot water heating, space heating, space cooling, and electricity. The performance parameters for the various IUS components (boilers, chillers, etc.) are also input, as well as the appropriate flags which describe the case being run. Program output consists of the calculated fuel utilization, generator output, chiller output, waste heat recovered, and energy to and from storage for each hour of the period under consideration.

The IUSMOD computer program used is a relatively simple analytical tool intended for preliminary sizing of storage schemes and rough estimates of the annual fuel utilization of alternative IUS designs. Results of the program appear to agree reasonably well with output from its more complex "parent" program, ESOP, when similar input data are used.

TABLE 1. EQUIPMENT DATA FOR NO-STORAGE BASELINE IUS

Item	1000-Unit Apartment	Village Complex
Diesel Generators		
Manufacturers	Fairbanks-Morse	Nordberg
Rating, kW	478	4,415
Number Installed	6	8
Total Capacity, kW	2,868	35,320
Absorption Chillers		
Installed Capacity, Tons	450	3,400
COP	0.6	0.6
Electric Chillers		
Installed Capacity, Tons	1,000	6,200
COP	4.0	4.0
Auxiliary Boilers		
Rating, hp	250	500
Number Installed	2	4
Total Capacity, hp	500	2,000
Efficiency, percent	80	80

Load Profiles

The load profiles for the IUS baseline communities were developed based on information supplied by NASA-JSC. The profiles consisted of the hour-by-hour demands for electricity, space heating, space cooling, and domestic hot water heating, and they defined the energy loads which the IUS baselines were required to supply. In addition, the quantity of thermal energy which was recoverable from the incineration of solid wastes was estimated based on an assumed constant burn rate during daylight hours. Profiles for six day types were developed representing a summer design day, a winter design day, and average days for spring, summer, fall, and winter for both the 1000-Unit Apartment and the Village Complex.

Tables 2 through 5 show the load profiles for summer and winter design days* for the 1000-Unit Apartment and the Village Complex. The electrical and cooling loads for the summer design day are shown graphically in Figures 2 and 3 for the 1000-Unit Apartment and the Village Complex respectively.

Framework for Assessment

The objective of this task was the development of a framework for evaluating the various alternative energy storage concepts. This task involved the selection of the various criteria for assessing the energy storage systems, establishment of a scoring system, and assignment of weighting factors for each criterion. The framework developed provides a means of summarizing the relative merits and shortcomings of the alternative schemes in a concise manner.

The framework devised is a modification to the method described by Churchman and Ackoff in Reference 3. The procedure involves the assignment of weights to each of the selected criteria according to their relative importance. The various alternatives are then evaluated against each of the assessment criteria and a raw score is assigned. The raw scores are multiplied by the weights

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* The design days are sometimes referred to as "2-Sigma" days, meaning they represent days in which the weather conditions are approximately 2 standard deviations higher than the average.

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TABLE 2. 1000-UNIT APARTMENT LOAD PROFILES--SUMMER DESIGN

HOUR	DOMESTIC HOT* WATER DEMAND (BTU/HR)	SPACE HEATING DEMAND (BTU/HR)	AIR COND. DEMAND (TONS)	DOMESTIC ELECT DEMAND (KW)	AUXILIARY ELECT DEMAND (KW)	OTHER HEAT RECOVERED (BTU/HR)
1 AM	7.44728E+05	0.	7.76418E+02	8.69840E+02	2.00000E+02	0.
2 AM	3.22520E+05	0.	7.32333E+02	7.84080E+02	1.94000E+02	0.
3 AM	3.10792E+05	0.	6.85155E+02	6.36080E+02	1.80000E+02	0.
4 AM	2.28596E+05	0.	6.59591E+02	6.36080E+02	1.76000E+02	0.
5 AM	2.28696E+05	0.	6.43875E+02	6.36080E+02	1.68000E+02	0.
6 AM	6.33312E+05	0.	7.41879E+02	6.36080E+02	1.76000E+02	0.
7 AM	2.37716E+06	0.	8.81439E+02	7.41860E+02	1.86300E+02	0.
8 AM	5.45504E+06	0.	9.69081E+02	8.5826CE+02	1.940C0E+02	4.57000E+06
9 AM	4.51388E+06	0.	1.05953E+03	8.27940E+02	1.960C0E+02	4.57000E+06
10 AM	1.51206E+06	0.	1.15710E+03	7.61840E+02	2.00000E+02	4.57000E+06
11 AM	3.44340E+06	0.	1.21520E+03	7.6384CE+02	2.16000E+02	4.57000E+06
NOON	3.59580E+06	0.	1.24442E+03	7.63840E+02	2.24000E+02	4.57000E+06
1 PM	1.66728E+06	0.	1.26094E+03	7.63840E+02	2.30000E+02	4.57000E+06
2 PM	1.60519E+06	0.	1.30921E+03	7.63840E+02	2.340C0E+02	4.57000E+06
3 PM	2.44280E+06	0.	1.34028E+03	7.63540E+02	2.44000E+02	4.57000E+06
4 PM	3.32634E+06	0.	1.35578E+03	7.63940E+02	2.60000E+02	4.57000E+06
5 PM	2.43433E+06	0.	1.33174E+03	9.29320E+02	2.70000E+02	4.57000E+06
6 PM	3.13590E+06	0.	1.29273E+03	1.22988E+03	2.50000E+02	4.57000E+06
7 PM	5.33436E+06	0.	1.16261E+03	1.48388E+03	2.88000E+02	4.57000E+06
8 PM	4.14468E+06	0.	1.08215E+03	1.68770E+03	3.00000E+02	0.
9 PM	5.07162E+06	0.	1.01506E+03	1.65770E+03	3.00000E+02	0.
10 PM	4.90297E+06	0.	9.70663E+02	1.68770E+03	3.00000E+02	0.
11 PM	3.25078E+06	0.	9.10715E+02	1.35988E+03	2.80000E+02	0.
MD-NT	1.51460E+06	0.	8.19947E+02	1.31982E+03	2.40000E+02	0.

* E +01 = $x10^1$

TABLE 3. 1000-UNIT APARTMENT LOAD PROFILES--WINTER DESIGN

HOURLY INPUT DATA FOR DAY 01 OF 01 ≡ WINTER 2-SIGMA DAY ≡ 1000 APART. ≡ WASH. D.C.

IDAY = 0 ISESON = 1 I = 0

HOUR	DOMESTIC HOT WATER DEMAND (BTU/HR)	SPACE HEATING DEMAND (BTU/HR)	AIR COND. DEMAND (TONS)	DOMESTIC ELECT DEMAND (KW)	AUXILIARY ELECT DEMAND (KW)	OTHER HEAT RECOVERED (BTU/HR)
1 AM	7.44728E+05	7.85524E+06	0.	8.69840E+02	2.00000E+02	0.
2 AM	3.22520E+05	8.17150E+06	0.	7.84080E+02	1.94000E+02	0.
3 AM	3.10792E+05	8.53195E+06	0.	6.36080E+02	1.80000E+02	0.
4 AM	2.28696E+05	8.79569E+06	0.	6.36080E+02	1.76000E+02	0.
5 AM	2.28696E+05	9.05703E+06	0.	6.36080E+02	1.68000E+02	0.
6 AM	6.33312E+05	9.21035E+06	0.	6.36080E+02	1.76000E+02	0.
7 AM	2.37716E+06	9.73223E+06	0.	7.41860E+02	1.86000E+02	0.
8 AM	5.45504E+06	9.19324E+06	0.	8.58260E+02	1.94000E+02	4.57000E+06
9 AM	4.81989E+06	9.18473E+06	0.	8.27940E+02	1.95000E+02	4.57000E+06
10 AM	1.51206E+06	9.02506E+06	0.	7.63840E+02	2.00000E+02	4.57000E+06
11 AM	3.44340E+06	8.82134E+06	0.	7.63840E+02	2.16000E+02	4.57000E+06
NOON	3.59580E+06	8.56013E+06	0.	7.63840E+02	2.24000E+02	4.57000E+06
1 PM	1.69728E+06	8.43993E+06	0.	7.63840E+02	2.30000E+02	4.57000E+06
2 PM	1.60519E+06	8.29037E+06	0.	7.63840E+02	2.38000E+02	4.57000E+06
3 PM	2.44280E+06	8.15374E+06	0.	7.63840E+02	2.44000E+02	4.57000E+06
4 PM	3.32634E+06	8.06425E+06	0.	7.63840E+02	2.60000E+02	4.57000E+06
5 PM	2.43433E+06	7.89757E+06	0.	9.29920E+02	2.70000E+02	4.57000E+06
6 PM	3.13590E+06	7.54561E+06	0.	1.22988E+03	2.80000E+02	4.57000E+06
7 PM	5.33436E+06	7.26778E+06	0.	1.48388E+03	2.88000E+02	4.57000E+06
8 PM	4.14468E+06	7.60647E+06	0.	1.68770E+03	3.00000E+02	0.
9 PM	5.07162E+06	6.88565E+06	0.	1.65770E+03	3.00000E+02	0.
10 PM	4.90297E+06	6.74762E+06	0.	1.65770E+03	3.00000E+02	0.
11 PM	3.25078E+06	7.56804E+06	0.	1.36988E+03	2.80000E+02	0.
MD-NT	1.91460E+06	7.52568E+06	0.	1.01982E+03	2.40000E+02	0.

TABLE 4. VILLAGE COMPLEX LOAD PROFILES--SUMMER DESIGN

HOUR	DOMESTIC HOT WATER DEMAND (BTU/HR)	SPACE HEATING DEMAND (BTU/HR)	AIR COND. DEMAND (TONS)	DOMESTIC ELECT DEMAND (KW)	AUXILIARY ELECT DEMAND (KW)	OTHER HEAT RECOVERED (BTU/HR)
1 AM	1.99144E+06	0.	3.23224E+03	1.31660E+04	1.79300E+03	0.
2 AM	8.73956E+05	0.	3.01723E+03	1.17209E+04	1.85100E+03	0.
3 AM	8.16236E+05	0.	2.94726E+03	1.14692E+04	1.90900E+03	0.
4 AM	6.27741E+05	0.	2.91211E+03	1.13446E+04	1.97200E+03	0.
5 AM	6.27741E+05	0.	2.91197E+03	1.13359E+04	2.01500E+03	0.
6 AM	1.68411E+06	0.	3.29164E+03	1.24741E+04	2.09000E+03	0.
7 AM	6.12333E+06	0.	4.37026E+03	1.76174E+04	2.14500E+03	0.
8 AM	1.50459E+07	0.	5.78715E+03	2.06952E+04	2.10000E+03	1.22400E+07
9 AM	1.47528E+07	0.	5.65562E+03	1.97954E+04	2.20000E+03	1.22400E+07
10 AM	8.08943E+06	0.	6.33455E+03	1.78549E+04	2.20000E+03	1.22400E+07
11 AM	1.16280E+07	0.	6.90834E+03	1.90369E+04	2.34000E+03	1.22400E+07
NOON	1.24112E+07	0.	7.19206E+03	2.03168E+04	2.40500E+03	1.22400E+07
1 PM	7.99364E+06	0.	7.47324E+03	2.11023E+04	2.33500E+03	1.22400E+07
2 PM	8.58871E+06	0.	8.07494E+03	2.14893E+04	2.66500E+03	1.22400E+07
3 PM	9.60864E+06	0.	8.58104E+03	2.03944E+04	2.82500E+03	1.22400E+07
4 PM	9.80844E+06	0.	8.80915E+03	2.09892E+04	3.02000E+03	1.22400E+07
5 PM	7.74147E+06	0.	9.30730E+03	2.15333E+04	3.18900E+03	1.22400E+07
6 PM	8.66646E+06	0.	9.30953E+03	2.27668E+04	3.04500E+03	1.22400E+07
7 PM	1.44949E+07	0.	8.78213E+03	2.60550E+04	2.79500E+03	1.22400E+07
8 PM	1.04766E+07	0.	6.31545E+03	2.49459E+04	2.58500E+03	0.
9 PM	1.22051E+07	0.	5.55122E+03	2.42069E+04	2.83500E+03	0.
10 PM	1.18917E+07	0.	4.83953E+03	2.25699E+04	2.59000E+03	0.
11 PM	8.57910E+06	0.	4.29039E+03	1.96461E+04	2.74500E+03	0.
MD-NT	5.14222E+06	0.	4.01223E+03	1.64291E+04	2.01500E+03	0.

TABLE 5. VILLAGE COMPLEX LOAD PROFILES--WINTER DESIGN

HOUR	DOMESTIC HOT WATER DEMAND (BTU/HR)	SPACE HEATING DEMAND (BTU/HR)	AIR COND. DEMAND (TONS)	DOMESTIC ELECT DEMAND (KW)	AUXILIARY ELECT DEMAND (KW)	OTHER HEAT RECOVERED (BTU/HR)
1 AM	1.99144E+06	5.15446E+07	0.	1.47525E+04	1.54500E+03	0.
2 AM	8.73556E+05	5.35561E+07	0.	1.31508E+04	1.55600E+03	0.
3 AM	8.16236E+05	5.39360E+07	0.	1.31392E+04	1.55500E+03	0.
4 AM	6.27741E+05	5.44526E+07	0.	1.32493E+04	1.57000E+03	0.
5 AM	6.27741E+05	5.51361E+07	0.	1.34649E+04	1.57500E+03	0.
6 AM	1.68411E+06	5.90191E+07	0.	1.43377E+04	1.57500E+03	0.
7 AM	6.12333E+06	5.88995E+07	0.	1.80865E+04	1.58600E+03	0.
8 AM	1.50459E+07	5.89719E+07	0.	2.04474E+04	1.48400E+03	1.22400E+07
9 AM	1.47528E+07	5.22814E+07	7.87543E+01	1.96563E+04	1.34900E+03	1.22400E+07
10 AM	8.08943E+06	5.05173E+07	2.14907E+02	1.66540E+04	1.42900E+03	1.22400E+07
11 AM	1.16280E+07	5.02178E+07	2.36715E+02	1.67235E+04	1.51800E+03	1.22400E+07
NOON	1.24112E+07	4.79301E+07	2.47946E+02	1.68470E+04	1.47400E+03	1.22400E+07
1 PM	7.99364E+06	4.67278E+07	2.59159E+02	1.65188E+04	1.52500E+03	1.22400E+07
2 PM	8.58871E+06	4.56341E+07	2.75770E+02	1.60444E+04	1.58500E+03	1.22400E+07
3 PM	9.60864E+06	4.51735E+07	2.58225E+02	1.48207E+04	1.60600E+03	1.22400E+07
4 PM	9.80844E+06	4.57229E+07	2.54225E+02	1.51690E+04	1.66300E+03	1.22400E+07
5 PM	7.74147E+06	4.92109E+07	2.54214E+02	1.56634E+04	1.69900E+03	1.22400E+07
6 PM	8.66646E+06	5.09977E+07	1.52973E+02	1.67474E+04	1.73600E+03	1.22400E+07
7 PM	1.44949E+07	4.78974E+07	8.22053E+01	2.03501E+04	1.61000E+03	1.22400E+07
8 PM	1.04766E+07	4.41976E+07	0.	2.00536E+04	1.54400E+03	0.
9 PM	1.22051E+07	4.25794E+07	0.	2.03199E+04	1.95800E+03	0.
10 PM	1.18907E+07	4.33956E+07	7.24824E+01	1.98429E+04	1.89700E+03	0.
11 PM	8.57910E+06	4.63929E+07	0.	1.80790E+04	1.67800E+03	0.
MD-NT	5.14222E+06	4.84369E+07	0.	1.61918E+04	1.63500E+03	0.

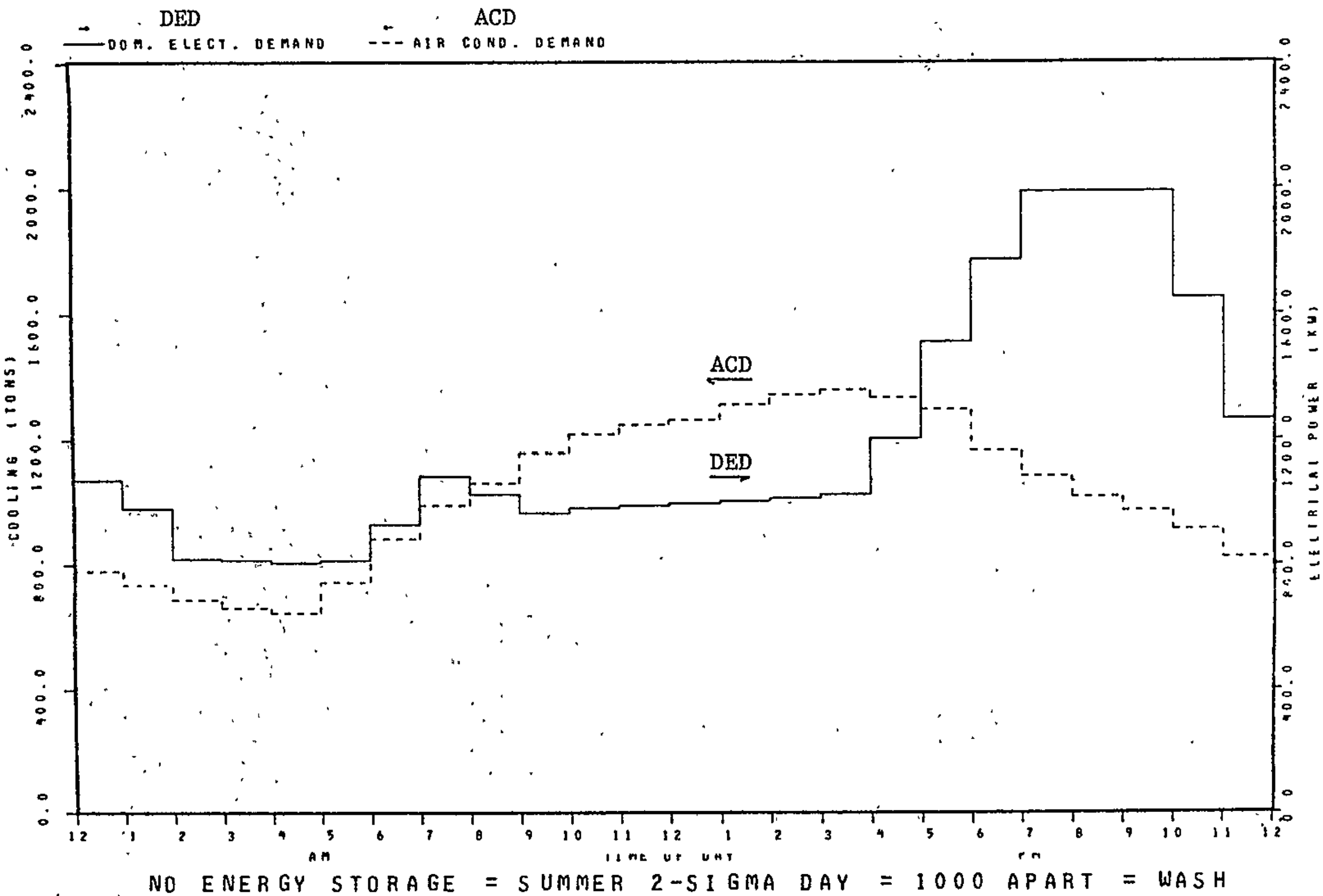

FIGURE 2. 1000-UNIT APARTMENT LOAD PROFILES

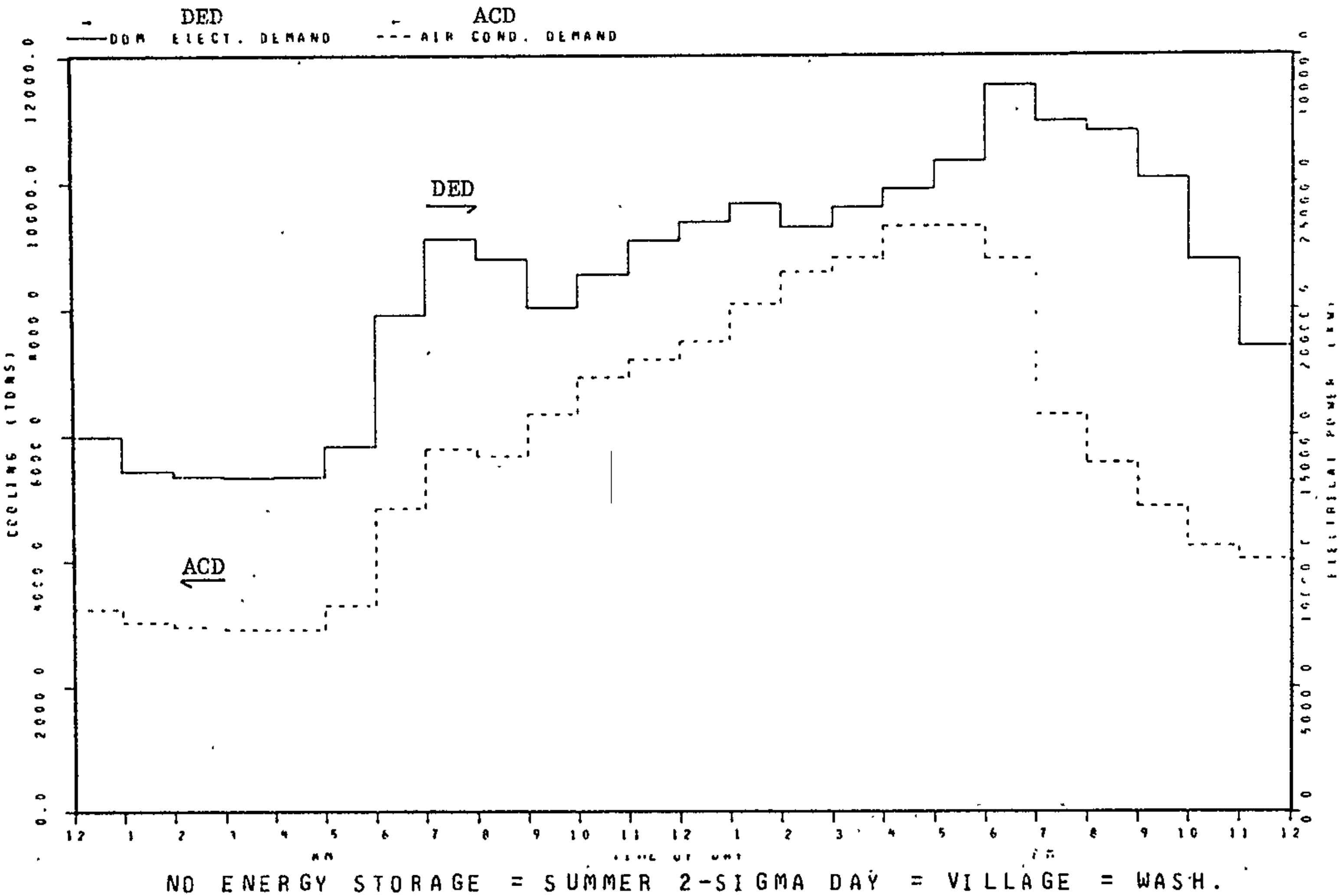

FIGURE 3. VILLAGE COMPLEX LOAD PROFILES

assigned to each criteria and the weighted scores summed for each alternative. The total weighted scores for the various alternatives may then be compared and a relative ranking determined.

Assessment Criteria and Scoring

The criteria which were utilized in assessing the relative merits of energy storage alternatives were selected based on a review of the overall objectives of the IUS program and discussions with NASA-JSC personnel. The selected assessment criteria are:

- Net relative cost
- Relative fuel utilization
- Safety
- Availability/Reliability/Maintainability
- Hardware availability
- Environmental concerns
- Energy storage density
- Expansion capability
- Transportability.

The evaluation framework selected requires that a system for assigning raw scores to each of the energy storage alternatives be established. The procedure utilized in devising this scoring system involved the evaluation of each of the energy storage alternatives relative to the no-storage baseline. A scale ranging from one through nine was selected and the no-storage case was arbitrarily assigned a value of five for each of the criteria. If an energy storage device was judged by the Project Team to yield a total system better than the no-storage case, a value greater than five was assigned. If inferior to no-storage, a value less than five was assigned.

The criteria which were utilized in this study are summarized in Tables 6 through 14. They are defined and their associated scoring scales are discussed in the following sections.

Net Relative Cost. Net relative cost (NRC) is the ratio of the life cycle cost of an IUS/energy storage combination to the life cycle cost of the baseline IUS concept. The term "net" emphasizes recognition of potential savings as well as the additional costs incurred by the incorporation of an energy storage device. The term life cycle cost is used here to indicate the properly discounted sum of the first costs and the operating and maintenance costs over the life of the project. It is not meant to include the developmental costs associated with the initial prototypes for any of the energy storage systems. The assumptions and procedures utilized in calculating the net relative cost of the energy storage devices are discussed in Appendix A.

Table 6 presents the scale which was selected for assigning scores to each of the energy storage candidates based on net relative cost. Notice that the scale has been centered around the demarcation value of 1.0. Devices with values of net relative cost greater than 1.0 will be less profitable than the no-storage baseline while values less than 1.0 refer to energy storage systems which improve profitability. The increment utilized in this scale is 1 percent. Thus, an energy storage device which results in a savings of 1 percent of the life cycle cost of the no-storage baseline will receive a score of 6. A device which will increase life cycle costs by 1 percent (NRC = 1.01) will receive a score of 4.

Relative Fuel Utilization. Relative fuel utilization is the ratio of annual fuel consumption of the IUS/energy storage combination to the annual fuel consumption of the no-storage baseline IUS. The fuel consumption scoring scale is presented in Table 7. As for net relative cost, the relative fuel utilization scale is centered around a value of 1.0 with 1 percent increments. Thus, an energy storage device which reduces the energy consumption of the IUS by 1 percent will be assigned a value of 6.

Safety. Safety is the relative freedom from accidental system failures that could endanger property and/or life. Safety can be quantified in terms of occurrences or consequences of unsafe system failures, i.e., incidents resulting in property damage and/or personal injury. Commonly used indices are

TABLE 6. NET RELATIVE COST SCORING SCALE

NRC[a]	Score
< 0.966	9
0.966 - 0.975	8
0.976 - 0.985	7
0.986 - 0.995	6
0.996 - 1.005	5
1.006 - 1.015	4
1.016 - 1.025	3
1.026 - 1.035	2
> 1.035	1

(a) Net Relative Cost (NRC) = $\dfrac{\text{Life cycle cost of IUS "with" energy storage}}{\text{Life cycle cost of IUS "without" energy storage}}$

TABLE 7. RELATIVE FUEL UTILIZATION SCORING SCALE

RFU[a]	Raw Score
< 0.966	9
0.966 - 0.975	8
0.976 - 0.985	7
0.986 - 0.995	6
0.996 - 1.005	5
1.006 - 1.015	4
1.016 - 1.025	3
1.026 - 1.035	2
> 1.035	1

(a) Relative Fuel Utilization (RFU) = $\dfrac{\text{Annual Fuel Utilization of IUS "with" storage}}{\text{Annual Fuel Utilization of IUS "without" storage}}$

(1) property damage value per unit interval of system operation and (2) number of injuries and/or fatalities per unit interval of system operation. These indices are measures of the "safety of a system" (as distinct from "system safety" which has special meaning).

For the particular case of assessing the safety of the IUS or its variants incorporating candidate energy storage devices, it was recognized that attempts at quantifying the safety of the systems would not be possible within the constraints of the study. A qualitative scale was therefore developed and is presented in Table 8.

Availability/Reliability/Maintainability. System availability is the probability that, under specified conditions, a system would be ready for use upon demand; it contains reliability and maintainability aspects. System reliability is the probability that a system would perform its functions when called upon to do so. It contains the random or unscheduled downtime element of availability. Maintainability is a design characteristic of a system that allows the system to be held in or restored to a state of readiness responsive to demand. It contains the scheduled downtime element of availability.

A qualitative scale was selected as a measure of this combined criterion. The scale is presented in Table 9.

Hardware Availability. Energy storage system hardware availability is an indication of the state of readiness of industry to produce a complete subsystem to specifications. This criterion is coarsely measurable in terms of the assembly/component/part that is most critical to the implementation of the subsystem. The qualitative scale for this criterion is shown in Table 10.

Environmental Concerns. Environmental concerns deal with the impacts of system installation and operation upon the maintenance of environmental quality. Included are resource utilization (e.g., land and water use) and environmental contamination/pollution (chemical, noise, electromagnetic interference). The qualitative scale used to score this criterion is presented in Table 11.

TABLE 8. SAFETY SCORING SCALE

	Score
Addition of energy storage device to IUS is judged to improve safety of total system	7
Addition of energy storage device to IUS is judged to neither improve nor diminish safety of system	5
Addition of energy storage device to IUS is judged to diminish somewhat the safety of the system	3
Safety problem of a magnitude likely to impair implementation of the storage device	1

TABLE 9. AVAILABILITY/RELIABILITY/MAINTAINABILITY SCORING SCALE

	Score
Addition of energy storage device to IUS judged to improve system availability/reliability/maintainability	7
Addition of energy storage device not expected to improve or impair system availability/reliability/maintainability	5
Addition of energy storage device judged to significantly impair system availability/reliability/maintainability	3

TABLE 10. HARDWARE AVAILABILITY SCORING SCALE

	Score
• Hardware considered "off-the-shelf"	5
• Hardware not considered "off-the-shelf", but is producible upon demand	4
• Hardware producible with technology judged to be within the state of the art	3
• Producible with advancement in the state of the art	2
• Not producible without significant RDT&E	1

TABLE 11. ENVIRONMENTAL CONCERNS SCORING SCALE

	Score
• Addition of energy storage device judged to reduce the environmental impact of the system	7
• Addition of the energy storage device judged to neither reduce or improve the environmental impact of the system	5
• Addition of the energy storage device expected to significantly increase the environmental impact of the system	3

Energy Storage Density. Energy storage density is the ratio of energy storage capacity (kWh) to the volume of the storage facility. Since this characteristic is intended to indicate the size of the energy storage device, care must be taken in the definition of the storage facility. For example, the thermal well storage concept (discussed in Volume III) utilizes naturally occurring aquifers as the storage medium. The volume of these aquifers is not chargable to the energy storage device since it does not affect the size of the installation. For battery systems, the calculation of energy storage density must include allowances for removal and replacement clearance which does effect the size of the installation.

Table 12 presents the scale which was utilized in scoring energy storage density. The scale was defined so that energy storage systems which are approximately the same size as the prime movers they would replace are assigned a score of 5. This is consistant with the philosophy of comparing all energy storage systems to the no-storage baseline. Energy storage systems which will require a volume approximately 10 times the volume of the prime mover replaced are assigned a score of 3, and systems requiring 100 times the volume are assigned a score of 1.

Expansion Capability. Expansion capability is a design characteristic of an energy storage subsystem that allows significant incremental upgrading of subsystem capacity. This involves the capability of adding duplicate units or redesigning/reworking/replacing the existing subsystem. Modularity of the storage facility is a key conceptual capability. Table 13 presents the scoring scale for this criterion.

Transportability. Transportability refers to the compatibility of energy storage equipment with modes of transportation from assembly plant to installation site. Modularity of equipment eases handling and shipment. In contrast, large inherently integral pieces of equipment could force significant amounts of field fabrication. The qualitative scoring scale for this criterion is presented in Table 14.

TABLE 12. ENERGY STORAGE DENSITY SCORING SCALE

ESD, kWh/m^3 [a]	Score
3,500	9
1,750 - 3,500	8
350 - 1,750	7
175 - 350	6
35 - 175	5
17.5 - 35	4
3.5 - 17.5	3
1.75 - 3.5	2
0.35 - 1.75	1

(a) Energy Storage Density ESD =

$$\frac{\text{Energy withdrawn from storage during complete discharge}}{\text{Volume of storage system}}$$

TABLE 13. EXPANSION CAPABILITY SCORING SCALE

	Score
Expansion capability of energy storage system judged to be superior to baseline system	7
Expansion capability of energy storage system judged to be approximately the same as the baseline system	5
Expansion capability of energy storage system judged to be less than the baseline system	3

TABLE 14. TRANSPORTABILITY SCORING SCALE

	Score
Commercial carrier delivery, SOA assembly/alignment	5
Specially constructed transportation equipment required or significant field fabrication	3
Transportability problems expected to severely limit application of the storage device	1

Weighting Factors. Table 15 presents the weighting factors for the assessment criteria. These factors were selected by the study team and reviewed by NASA-JSC personnel. They represent the best judgment of these researchers as to the importance of each of the assessment criteria in the near term. Other weights and scoring systems may be more appropriate for energy storage applications other than IUS or as the importance of each criteria changes with time.

TABLE 15. WEIGHTING FACTORS FOR ASSESSMENT CRITERIA

Criteria	Weight
Net relative cost	2.0
Relative fuel utilization	1.4
Safety	1.2
Availability/Reliability/Maintainability	1.1
Hardware availability	1.1
Environmental concerns	0.8
Energy storage density	0.6
Expansion capability	0.6
Transportability	0.2

IUS SYSTEM STUDIES

Prior to initiating the detailed assessment of the individual energy storage technologies, a number of investigations were carried out which can be classified as IUS system studies. The objectives of these studies were to (1) define no-storage baseline performance in response to the load profiles, (2) identify and assess methods of integrating energy storage systems with the IUS baselines, (3) estimate the energy storage capacity, charge rates, and discharge rates required and, (4) estimate the energy saving resulting from the application of energy storage.

The procedure utilized in carrying out these system studies was to calculate (via the IUSMOD computer program described in Appendix B) the energy requirements and operating parameters of the no-storage baselines and energy storage options based on the load profiles defined in Task 2. Since these load profiles represent particular service requirements (the 1000-Unit Apartment and the Village Complex) in a particular climate (Washington, D.C.), the conclusions drawn from these system studies are strictly valid only for these or similar IUS applications. The effects of alternate climates on a thermal storage system applied to the 1000-Unit Apartment are addressed in a later section of this report.

No-Storage Baseline Performance

The results of the computer simulations for the no-storage baselines are summarized in Table 16 for the 1000-Unit Apartment and the Village Complex. An important result of these computer runs is the determination of the fuel requirement for the auxiliary boilers. The 1000-Unit Apartment consumes approximately 70 m^3 (18,500 gallons) of fuel per year for auxiliary heating. This represents approximately 2 percent of the total annual fuel consumption. The Village Complex auxiliary boilers consume approximately 335 m^3 (88,400 gallons) per year or about 1 percent of the total.

TABLE 16. SUMMARY OF PERFORMANCE OF NO-STORAGE IUS

(A) 1000-Unit Apartment

Item	Day Type: Winter Design	Summer Design	Winter Average	Spring Average	Summer Average	Autumn Average	Annual
Total fuel consumption, thousands of gallons	3.159	3.367	2.390	2.188	2.642	2.200	860
Auxiliary boiler consumption, thousands of gallons	0.975	0.0	0.206	0.0	0.0	0.0	18.5
Electrical energy generated, MWh	28.6	44.4	28.6	28.7	34.8	28.9	11,050
Peak electrical demand, kW	1,988	2,729	1,988	2,009	2,404	2,017	2,729
Absorption cooling, thousand ton-hours	0.	6.72	0.	2.72	5.46	3.36	1,058
Compression cooling, thousand ton-hours	0.	17.9	0.	0.06	7.02	0.26	675
Peak compression cooling rate, tons	0.	974	0.	24	473	56	974

(B) Village Complex

Item	Day Type: Winter Design	Summer Design	Winter Average	Spring Average	Summer Average	Autumn Average	Annual
Total fuel consumption, thousands of gallons	32.3	38.5	24.0	19.9	24.6	19.7	8,047
Auxiliary boiler fuel consumption, thousands of gallons	3.04	0.	0.88	0.10	0.	0.	88.4
Electrical energy generated, MWh	441	580	348	299	371	296	119,900
Peak electrical demand, MW	22.3	33.6	19.1	17.7	25.3	17.1	33.6
Absorption cooling, thousand ton-hours	0	56.6	5.97	15.8	36.4	17.7	6,960
Compression cooling, thousand ton-hours	2.4	83.7	0.56	2.0	31.0	4.9	3,532
Peak compression cooling rate, tons	275	6,094	69	534	2,864	1,204	6,094

The peak electrical demand for the baseline cases occurs on the summer design day due to the electrical energy required for compression air-conditioning. The 1000-Unit Apartment IUS has a peak demand of 2729 kW which requires 6 of the 478 kW generator sets selected for this application. The Village Complex peak demand is 33,600 kW which means that 8 of the 4415 kW generator sets are required.

The peak compression cooling load for the 1000-Unit Apartment is 974 tons while the Village Complex requires a peak of 6094 tons.

Figures 4 through 7 are plots showing the hour-by-hour variation of several of the important parameters for the winter and summer design (or 2-Sigma) days.

Integration Techniques

An important task which was carried out early in the study was the identification and assessment of possible methods of integration of energy storage devices with the IUS baselines. Three of the methods identified appeared to be feasible and are loosely referred to as "electrical storage", "heat storage", and "cold storage". The locations of these integration concepts within the IUS are depicted by the dashed-border blocks shown in Figure 8. The operational procedure, advantages, and disadvantages of each of these integration concepts are discussed in the following paragraphs.

Electrical Storage

Electrical* storage systems are charged by drawing electrical energy from the IUS bus bar during periods when the generation capacity is greater than the demand. The devices are discharged during periods when the demand exceeds the installed generation capacity. Thus, the storage system acts as a "peak shaving" device in that the peak demand which the generation plant must meet is

* The term "electrical storage" is taken here to refer to the method of integration and not the form of the energy in storage. Flywheels, batteries, and compressed air may all be treated as electrical storage devices for integration purposes.

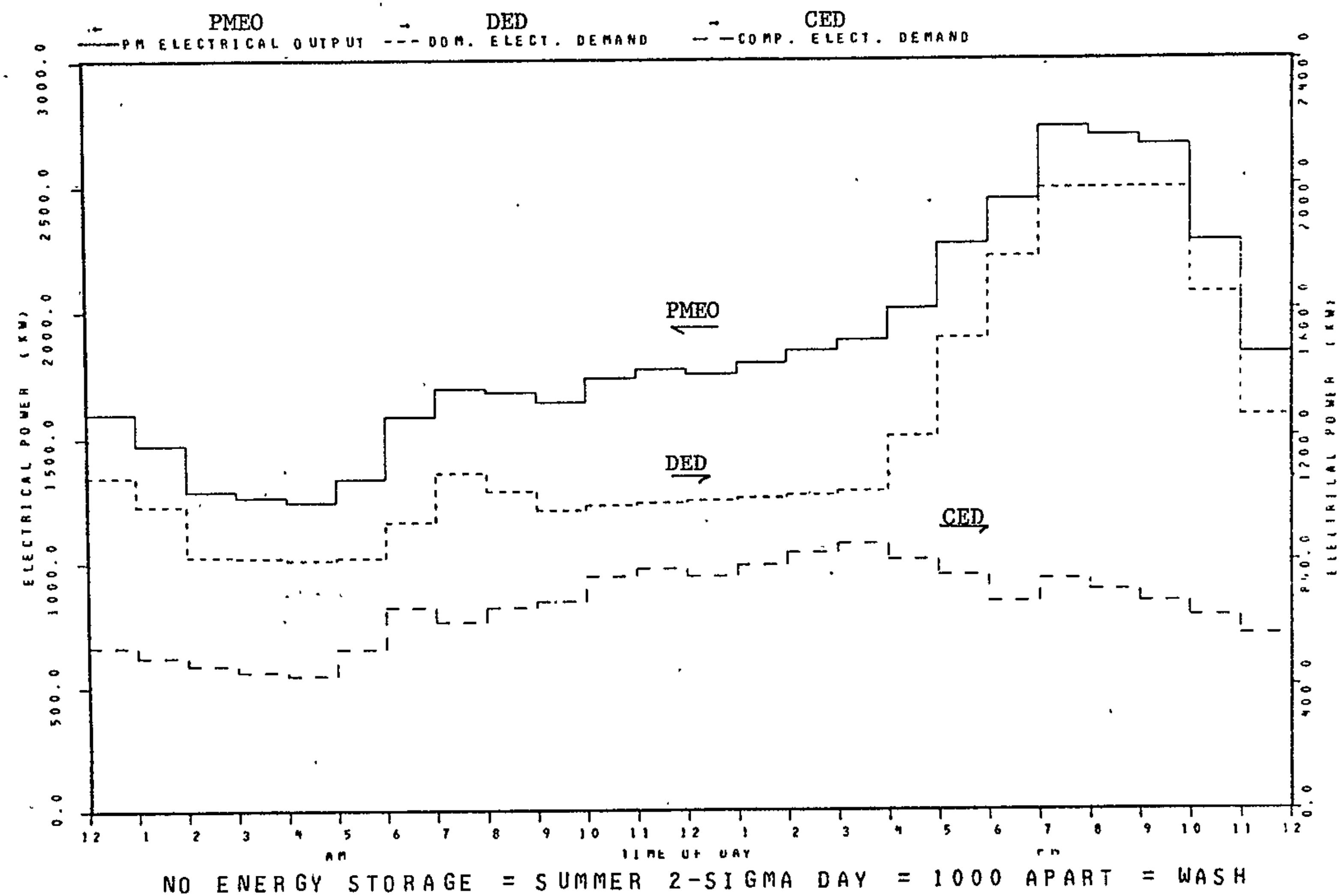

FIGURE 4. 1000-UNIT APARTMENT BASELINE PERFORMANCE (SUMMER)

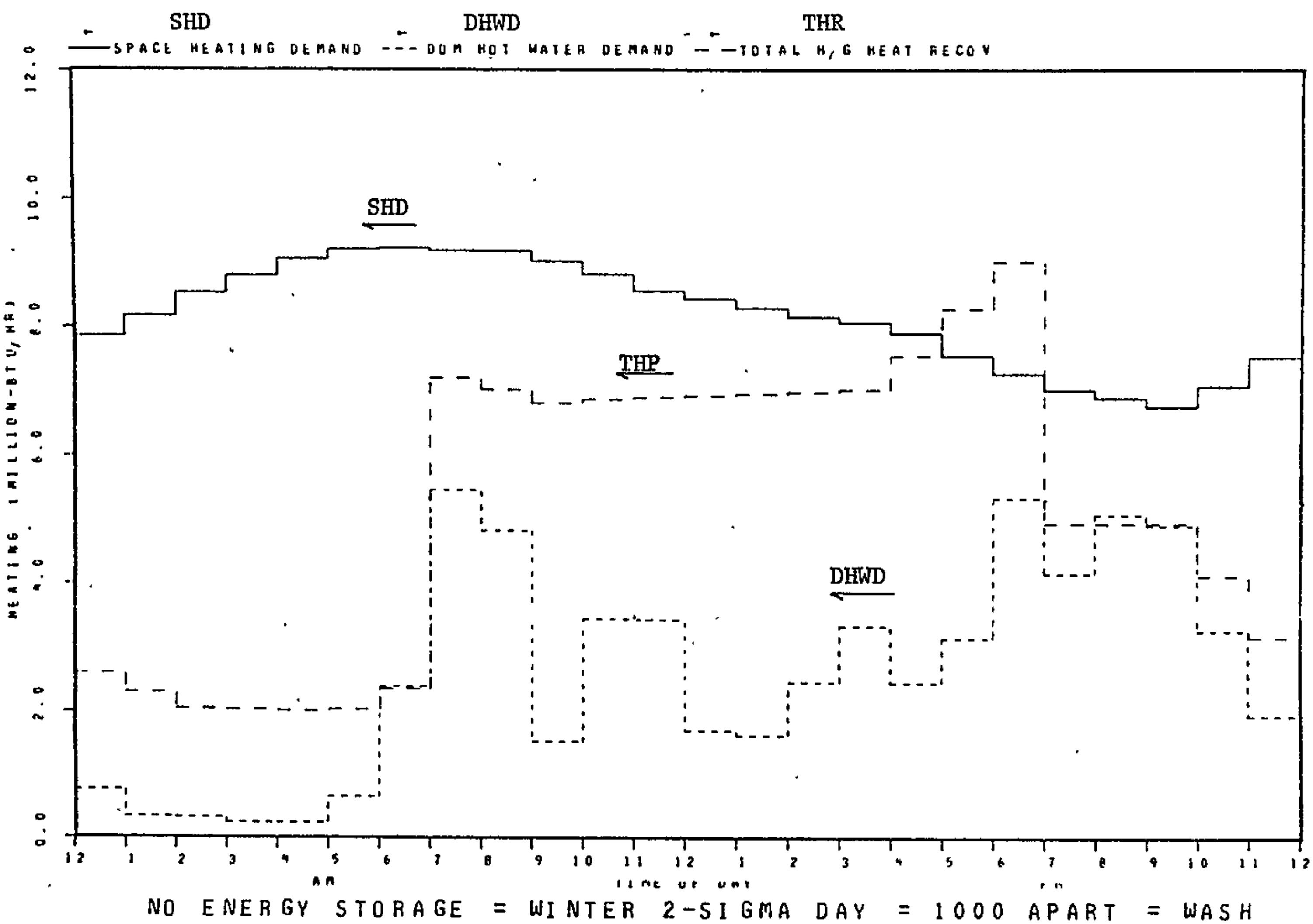

FIGURE 5. 1000-UNIT APARTMENT BASELINE PERFORMANCE (WINTER)

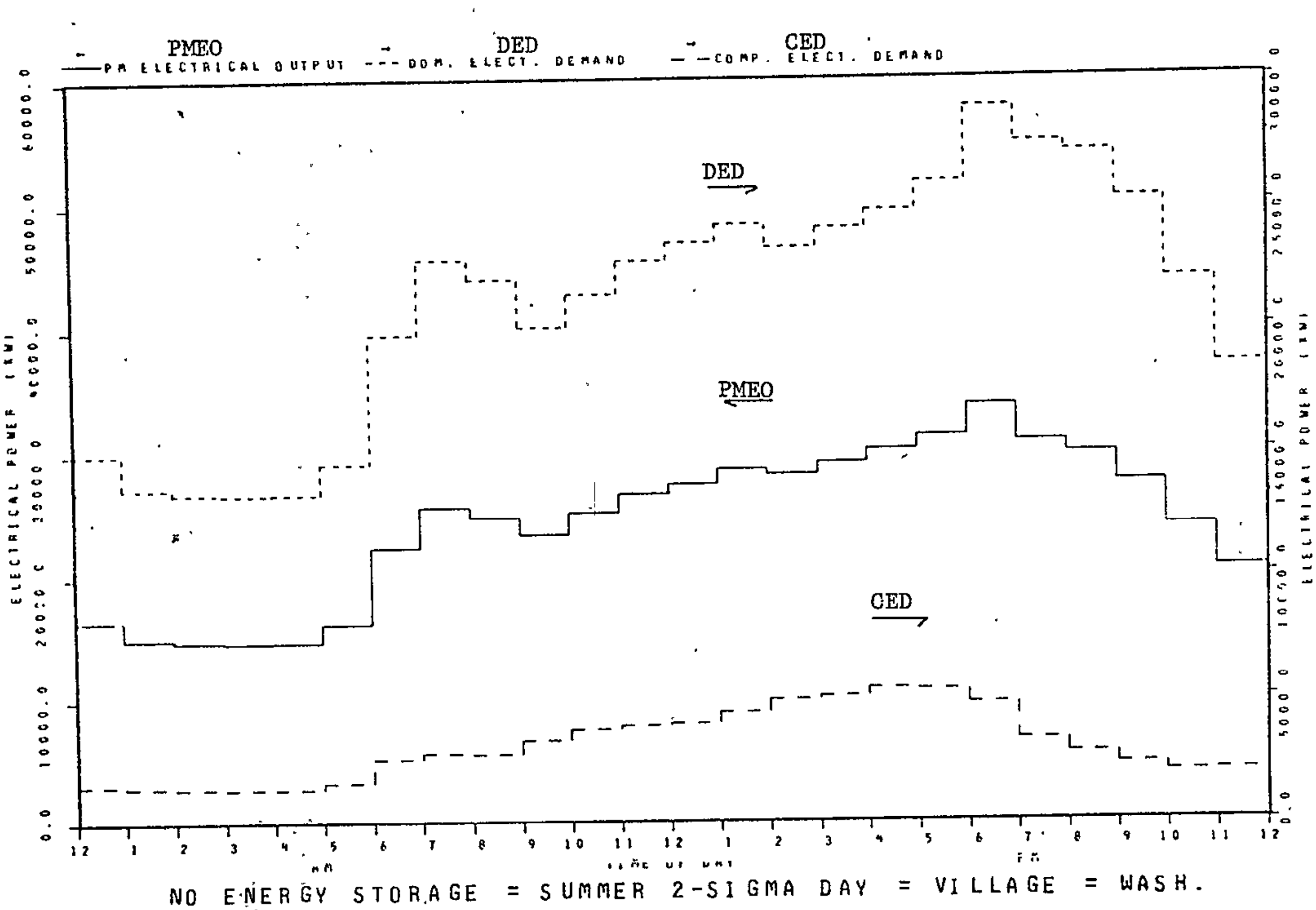

FIGURE 6. VILLAGE COMPLEX BASELINE PERFORMANCE (SUMMER)

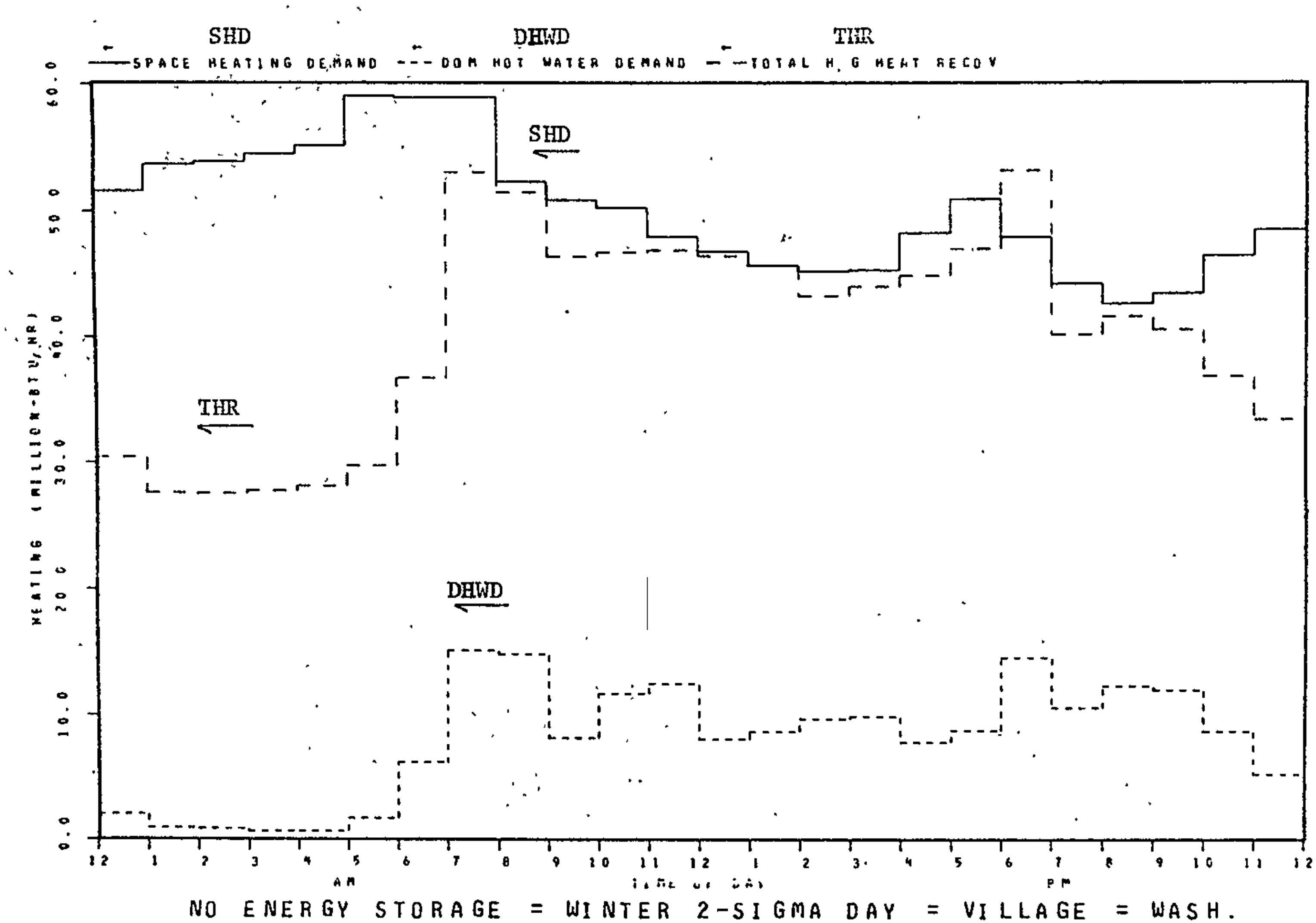

FIGURE 7. VILLAGE COMPLEX BASELINE PERFORMANCE (WINTER)

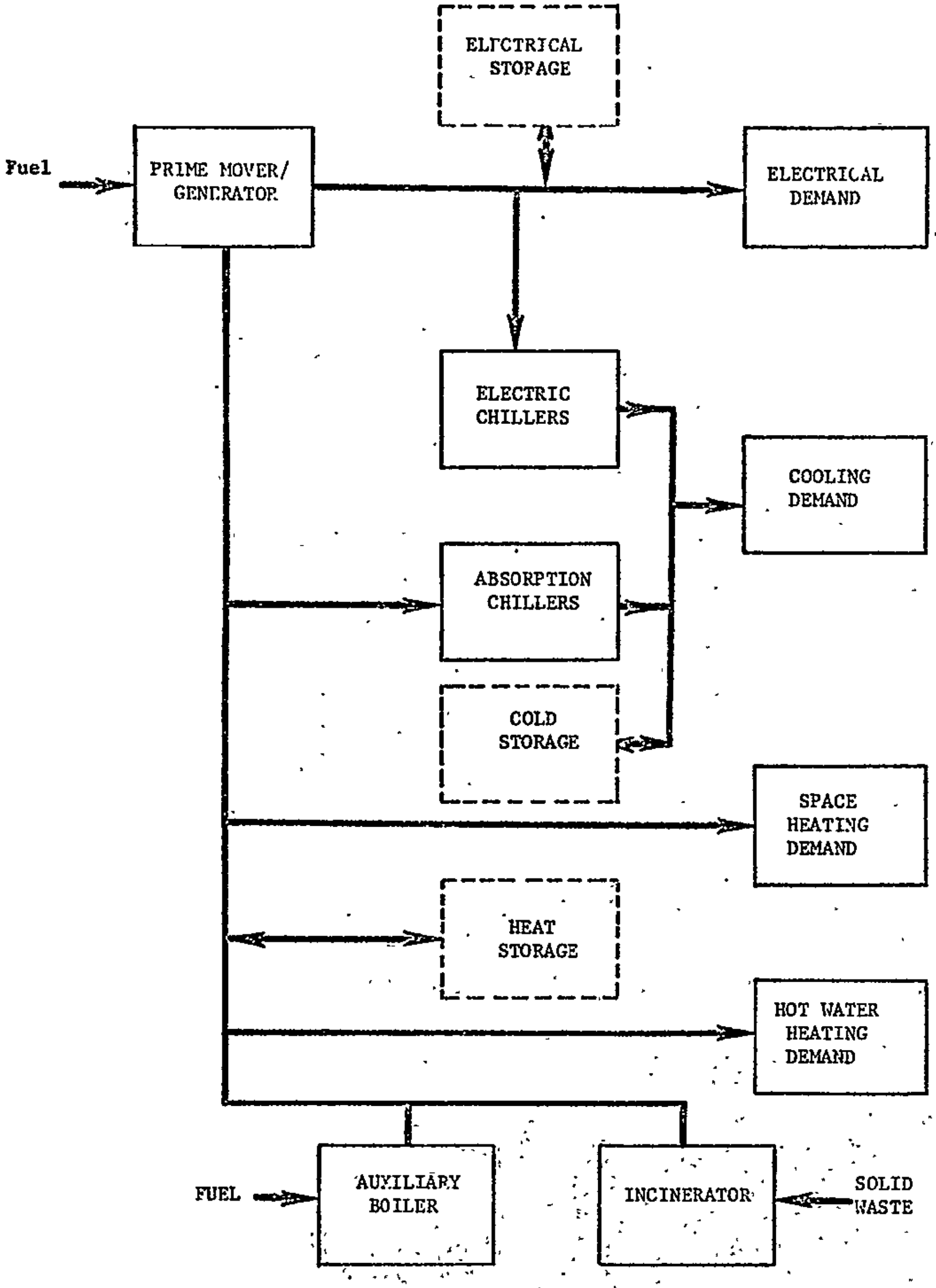

FIGURE 8. IUS/ENERGY STORAGE INTEGRATION TECHNIQUES

reduced due to the addition of an energy storage device. The concept is illustrated in Figure 9 for a typical electrical load profile. As illustrated in this figure, it is assumed that the charging cycle would begin immediately following the discharge cycle and would continue at the maximum rate (as dictated by the difference between the installed capacity and the electrical demand) until the storage device is completely recharged. This procedure would tend to provide a degree of stand-by capacity to satisfy unexpected power demands.

The advantages of this mode of operation include the improvement of the load factor of the generation plant. Load factor is defined as the ratio of the average power output of a plant over a specified time interval divided by the peak demand. Generally, improvements in the load factor of a plant result in increased generation efficiency since the plant will be operating fewer hours at off-design conditions. Another advantage is the possible cost savings due to the reduced generation capacity required. It should be pointed out, however, that cost savings will only accrue if the installed first cost of the energy storage device is less than the cost of the generating equipment being replaced. This follows since it was found that the addition of an energy storage device in the selected IUS applications has little effect on yearly fuel consumption.

It was originally thought that the "peak shaving" technique described above would result in some reduction in auxiliary fuel required due to the increased generator load at the off-peak hours when the thermal demands were greater. Examination of the load profiles, however, revealed that "peak shaving" electrical storage would only be used significantly during the summer months when electrical requirements are greatest. Since no auxiliary fuel is required during the summer, it was apparent that no auxiliary fuel reductions would be realized.

Another mode of operation (referred to in this study as Mode-3 storage) utilizing electrical storage was considered in an attempt to reduce auxiliary fuel consumption. The Mode-3 concept hypothesized was to operate the prime mover/ generator in such a manner as to satisfy the thermal loads, while using the electrical storage device to "balance" the electrical loads. During periods of high thermal demand and low electrical demand, the prime movers would be operated

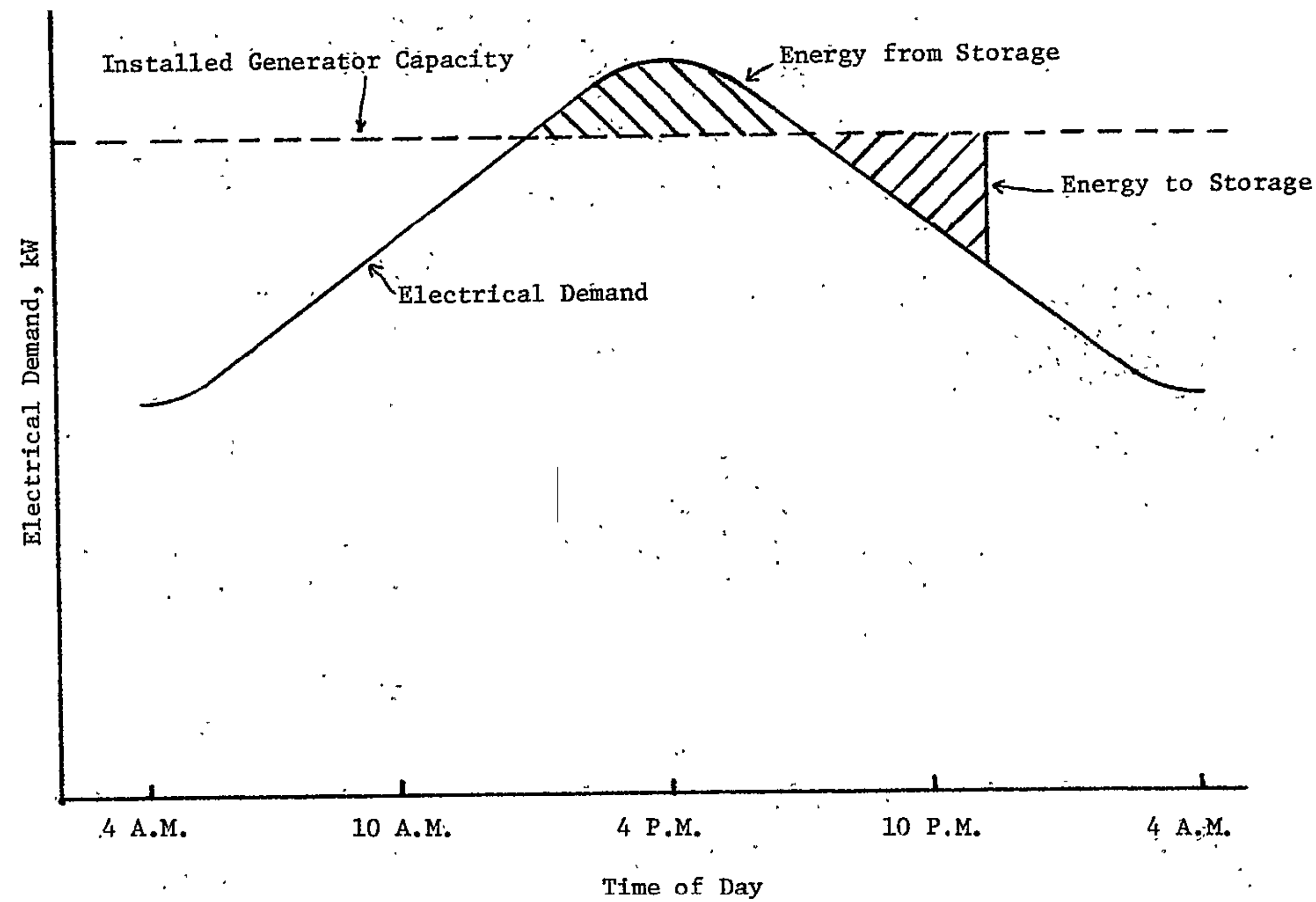

FIGURE 9. TYPICAL LOAD PROFILE FOR IUS UTILIZING ELECTRICAL ENERGY STORAGE

at a high load (thereby increasing the recovered heat and satisfying the thermal demand without consuming auxiliary fuel) and excess electrical energy would be stored. When thermal demands are low, electrical generation would be cut back and electrical energy would be drawn from the storage device.

It was apparent that the potential advantages of Mode-3 storage would be realized only during the winter months since during summer the operation is similar to the "peak shaving" technique. Moreover, excess thermal energy is nearly always available during the spring and autumn. During winter, auxiliary energy is normally required and the question becomes one of whether it is more efficient to generate this extra thermal energy via an auxiliary boiler or by means of the generator set/electrical storage combination. Analysis of the results of the computer simulations reveals that, in most cases, conventional electrical storage with an auxiliary boiler and Mode-3 storage will provide the required thermal energy with approximately equal efficiencies. However, the electrical storage concept will not allow the replacement of the auxiliary boiler since it will still be necessary to supply energy on the winter design days. It was, therefore, apparent that this integration concept would not offer advantages over the "peak shaving" concept described earlier and it was eliminated from further consideration.

Heat Storage

Heat storage systems would be charged during periods when the thermal energy recovered from the prime mover and the solid waste exceeds the requirements for space heating, space cooling, and domestic hot water heating. The systems would store thermal energy for use during periods when the thermal demand is greater than recovered thermal energy. Thus, a properly sized thermal storage system would eliminate the necessity for supplying thermal energy via an auxiliary boiler. The primary advantage of heat storage is therefore the reduction of the energy requirements of the IUS.

Cold Storage

The final integration concept which was identified as having possible application to IUS is termed "cold storage". This type of storage system would be charged during the hours when excess generation capacity is available. The

excess capacity would be used to power electric chillers and the excess "cold" would be placed in storage. The stored energy would then be used at a later time to supply peak cooling requirements. The cold storage concept, like electrical storage, is basically a means of shaving the peaks from the electrical demand profile. The same advantages (i.e., improved load factors and reduced generation capacity required), therefore, apply. Cold storage has the additional advantage of increasing the coefficient of performance of the chillers due to increased operation during periods of the day when ambient temperatures are lower. The potential savings due to this increased COP could not, however, be evaluated in this study because of limitations in the IUSMOD computer program.

Mechanical Storage

A number of the energy storage concepts assessed in this study involved the utilization of mechanical energy at some point in the storage process. In particular, inertial energy storage (flywheels) and compressed air storage are mechanical energy storage concepts. The possibility of utilizing the mechanical energy directly and thereby eliminating necessary conversions to and from electrical energy was, therefore, considered. It was determined, however, that attempts to integrate mechanical energy storage devices directly would not be justifiable due to the difficulties involved in controlling the flow of mechanical energy in a modular system such as IUS. For the purposes of this study the flywheel and compressed air storage concepts were, therefore, considered to be only "electrical" storage devices in that electrical energy is produced during discharge and absorbed during charge.

IUS/Energy Storage Performance

Estimates of the capacity and the performance characteristics of the energy storage devices as integrated with the IUS baselines were required so that technical and cost characteristics could be developed in the assessment tasks. This was accomplished through the use of the IUSMOD computer program which was developed during the study and is described in Appendix B.

Electrical Storage

Table 17 summarizes the results of the electrical storage series of computer runs for a range of round-trip efficiencies* which were thought to bracket those encountered in practical devices. Examination of the data presented reveals that the daily fuel utilization of the IUS is not affected to a great extent by the addition of electrical energy storage. This is due to the modular nature of the generation facilities which permits high generation efficiencies even at low load factors. In addition, an extra energy requirement is placed on the generation system as a result of the inefficiencies of the storage device. The net result is that the fuel utilization of the IUS/ES combination is increased slightly due to the use of electrical energy storage with the less efficient energy storage devices showing a greater increase. It, therefore, becomes evident that this method of energy storage will only be feasible if the installed cost of the storage device is less than the installed cost of the generator capacity which is replaced.

As indicated in Table 17, the energy which is withdrawn from the storage devices ranges from about 1 MWh for the 1000-Unit Apartment case with 5 generators to a maximum of about 34 MWh for the Village Complex with 6 generators. The actual energy storage capacity required will be greater than this by an amount corresponding to the discharge efficiency of the storage device. The energy supplied to the device during charging will differ from the energy delivered during discharge by the round-trip efficiency. It should be noted that the capacities given in the table for the 1000-Unit Apartment, 4 generator cases of 70 percent efficiency and below are based on supplying three consecutive design days. For these cases, the amount of energy available for charging is not quite sufficient to recharge the storage device during a design day. Storage capacity must therefore be increased to account for the difference.

* The round-trip efficiency of a storage device is defined as the ratio of the energy delivered from the storage device during discharge to the energy required by the device during charge.

TABLE 17. SUMMARY OF ELECTRICAL ENERGY STORAGE CAPACITIES

Case No.	Number of Generators Installed	Installed Generation Capacity, kW	Storage Efficiency, Round Trip	Storage Capacity Required, kWh	Energy Withdrawn From Storage During Day, kWh	Energy Supplied to Storage During Day, kWh	Maximum Discharge Rate, kW	Maximum Charge Rate, kW	Hours of Discharge	Hours of Charge	Hours Hold	Daily Fuel Consumption, gal
					1000 Apartments							
No Storage	6	2,868	–	–	–	–	–	–	–	–	–	3,367
05A	5	2,390	50	1,493	1,056	2,112	374	887	4	4	16	3,436
05B	5	2,390	70	1,261	1,056	1,507	374	739	4	3	17	3,396
05C	5	2,390	90	1,113	1,056	1,172	374	633	4	3	17	3,373
05D	4	1,912	50	9,062	4,065	5,790	905	750	7	17	0	3,480
05E	4	1,912	60	6,761	4,065	5,790	905	750	7	17	0	3,480
05F	4	1,912	70	4,878	4,065	5,790	905	750	7	17	0	3,480
05G	4	1,912	80	4,547	4,065	5,086	905	750	7	12	5	3,433
05H	4	1,912	90	4,283	4,065	4,513	905	750	7	10	7	3,394
					Village Complex							
No Storage	8	35,320	–	–	–	–	–	–	–	–	–	38,469
07A	7	30,905	50	4,496	3,179	6,360	2,921	3,764	2	4	18	38,657
07B	7	30,905	70	3,798	3,179	4,537	2,921	3,083	2	3	19	38,546
07C	7	30,905	90	3,350	3,179	3,530	2,921	2,075	2	3	19	38,484
07D	6	26,490	50	47,582	33,638	67,301	7,696	12,762	11	7	6	40,506
07E	6	26,490	70	40,191	33,638	48,019	7,696	12,675	11	6	7	39,325
07F	6	26,490	90	35,448	33,638	37,353	7,696	12,409	11	5	8	38,675

Heat Storage

Capacities required for heat storage systems were calculated utilizing the IUSMOD computer program and the results obtained are summarized in Table 18. The storage capacities shown were based on a single winter design day and an assumption that the storage device was fully charged at the beginning of the day. The heat storage capacity which is installed in a particular IUS application would depend on a determination of the number of consecutive design days which must be supplied. This determination was not performed in this study since storage size was, for most thermal storage systems, dictated by the cold storage requirement.

It should be pointed out that the data presented in Table 18 essentially represent energy balances on the storage system which do not account for such variables as the temperature of storage or the flow rates required. An exception to this approach was that only excess high grade energy would be added to storage. Excess low grade energy would be discarded. The reasoning behind this assumption was that there are many hours when excess low grade energy is available, but there is a simultaneous requirement for extra high grade energy (due to temperature considerations within the IUS). Thus, the addition of low grade energy to storage would not be possible. Energy from storage can, however, be used to satisfy both high and low grade demands. This question will be addressed in more detail in the integration section of the report.

Cold Storage

Capacities required for cold storage systems are based on the summer design days and are presented in Table 19. As for the heat storage case, these capacities were calculated from an energy balance viewpoint and do not take temperature effects into consideration. The 1000-Unit Apartment capacities were calculated assuming the replacement of two of the six generator sets which would be required for the no-storage baseline. The Village Complex calculation involved the removal of only one of the original eight generator sets. Further reduction was not possible for this case due to the necessity of meeting the peak domestic electrical demand.

TABLE 18. SUMMARY OF HEAT STORAGE CAPACITIES

Item	1000-Unit Apartment	Village Complex
Storage Capacity,[a] GJ	117	359
(Millions of BTU)	(111)	(341)
Maximum Discharge Rate,[a] (MW)	2.3	9
(Millions of BTU/hr)	(8.0)	(31)
Maximum Charge Rate,[b] (MW)	1.2	2.5
(Millions of BTU/hr)	(4.0)	(8.7)

(a) Based on winter design day.
(b) Based on winter average day.

TABLE 19. SUMMARY OF COLD STORAGE CAPACITIES

Item	1000-Unit Apartment[a]	Village Complex[b]
Storage Capacity, GJ	55	224
(ton-hours)	(4,350)	(17,700)
Maximum Discharge Rate, Tons	888	3,343
Maximum Charge Rate, Tons	533	2,184
Compression chiller capacity required, Tons	980	3,600

Comparison of the chiller capacities required with capacity requirements for the no-storage baselines (Table 1) reveals that only a minor reduction in capacity (from 1000 to 980 tons) is possible for the 1000-Unit Apartment. A reduction of approximately 2600 tons is possible for the Village Complex.

The capacities for cold storage reported in Table 19 were calculated based on the requirement that the storage be sufficient to supply cooling for continuous design days. This requirement determined the compression chiller capacity required since the chiller must recharge the storage completely each design day. The possibility of reducing the installed compression capacity by means of installing extra storage capacity was investigated for the 1000-Unit Apartment case. It was assumed that, for the purposes of this trade-off study, storage capacity should be sized to cover three consecutive design days.

The results of this investigation subtask are presented in Figure 10. This figure shows the storage capacity required as a function of installed compression chiller capacity. The sharp "knee" of the curve represents the point beyond which further increases in the compression capacity do not result in the reduction of storage capacity required. To the left of this point, a decrease in the compression capacity results in a sharp increase in the storage capacity required. The plot shows that a reduction of approximately 10 percent in chiller capacity must be accompanied by a doubling in the storage capacity required to satisfy the three consecutive day criteria. It was therefore concluded that decreases in the chiller capacity over that required to recharge the energy storage system fully during a design day would not be feasible.

Performance Summary

The fuel consumption values of the various IUS/energy storage combinations are given in Table 20 for the 1000-Unit Apartment and in Table 21 for the Village Complex. It should be pointed out that the cases referred to as thermal storage involve heat storage for autumn, winter, and spring days and cold storage for the summer days. It is interesting to note that only thermal storage results in the reduction of IUS annual fuel utilization. The magnitude of this reduction is estimated to be about 2 percent for the 1000-Unit Apartment and about 1 percent for the Village Complex.

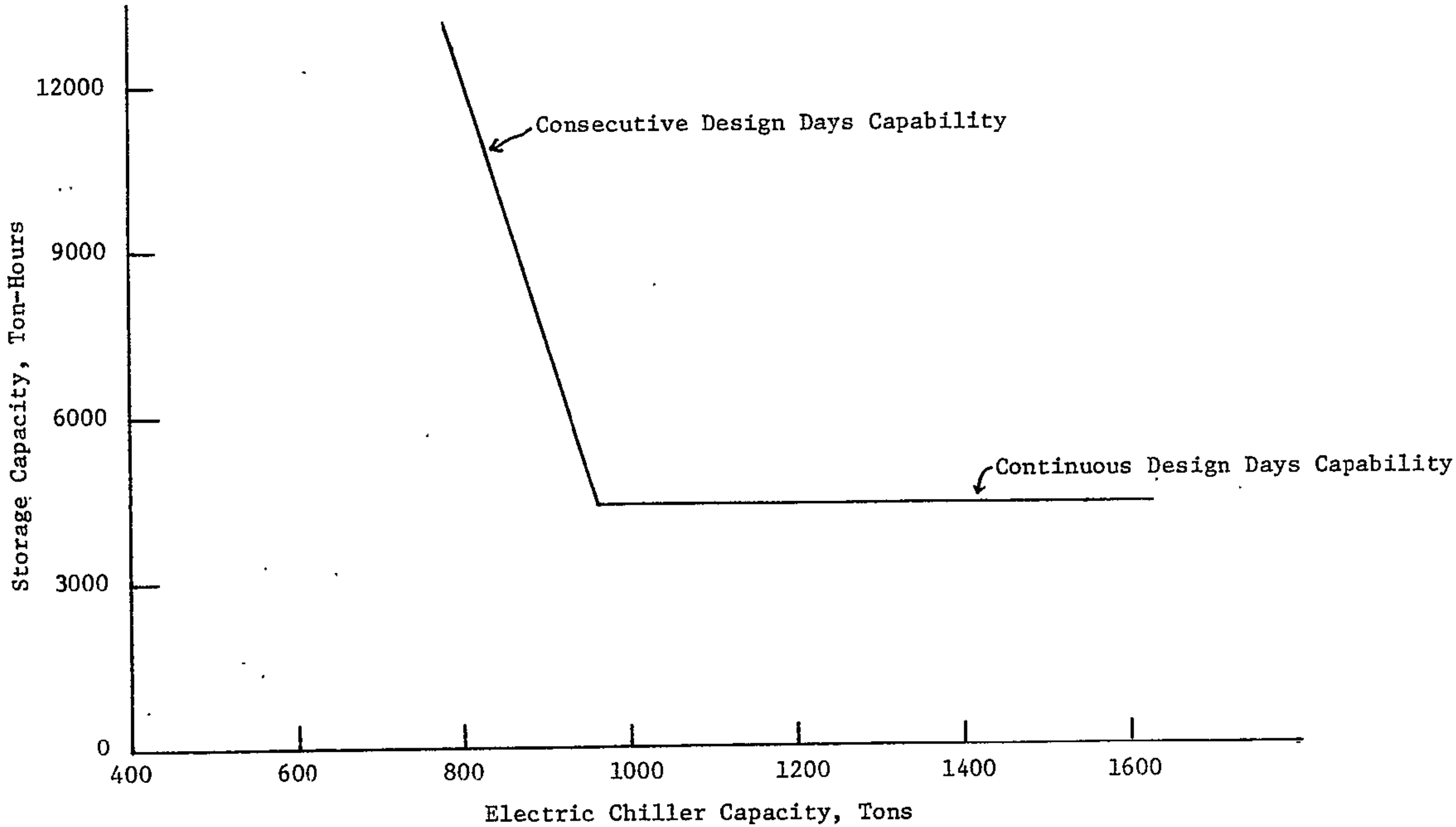

FIGURE 10. CHILLER CAPACITY--STORAGE CAPACITY TRADE-OFF

TABLE 20. SUMMARY OF FUEL USAGE, 1000 APARTMENTS

Case	Fuel Usage[1], thousands of gallons						
	Day Type						
	Winter Design	Summer Design	Winter Average	Spring Average	Summer Average	Autumn Average	Annual
No Storage	3.159	3.367	2.390	2.188	2.642	2.200	860
Thermal Storage (4 generators)	2.186	3.371	2.186	2.188	2.632	2.201	840
Electrical Storage (5 generators)							
η = 90%	3.159	3.373	2.390	2.188	2.644	2.200	860
η = 70%	3.159	3.396	2.390	2.188	2.644	2.200	860
η = 50%	3.159	3.436	2.390	2.188	2.644	2.200	860
Electrical Storage (4 generators)							
η = 90%	3.157	3.394	2.390	2.192	2.662	2.204	862
η = 70%	3.160	3.480[2]	2.394	2.199	2.705	2.212	868
η = 50%	3.169	3.480[2]	2.402	2.213	2.781	2.226	878

(1) Based on continuous days of each day type.

(2) Generator sets as operating at 100% full load at all times.

TABLE 21. SUMMARY OF FUEL USAGE, VILLAGE COMPLEX

Case	Fuel Usage[1], thousands of gallons						
	Day Type						
	Winter Design	Summer Design	Winter Average	Spring Average	Summer Average	Autumn Average	Annual
No Storage	32.3	38.5	24.0	19.9	24.6	19.7	8047
Thermal Storage (7 generators)	29.3	38.5	23.1	19.9	24.7	19.7	7975
Electrical Storage (7 generators)							
η_{RT} = 90%	32.3	38.5	24.0	19.9	24.6	19.7	8047
η_{RT} = 70%	32.3	38.5	24.0	19.9	24.6	19.7	8047
η_{RT} = 50%	32.3	38.7	24.0	19.9	24.6	19.7	8047
Electrical Storage (6 generators)							
η_{RT} = 90%	32.3	38.7	24.0	19.9	24.6	19.7	8047
η_{RT} = 70%	32.3	39.3	24.0	19.9	24.6	19.7	8047
η_{RT} = 50%	32.3	40.5	24.0	19.9	24.6	19.7	8047

(1) Based on continuous days of each day type.

The fuel use summaries in Table 20 also demonstrate the effect of round trip efficiencies of the electrical storage devices on the annual fuel consumption. Although low efficiency increases the consumption slightly for the summer design day, the effect is reduced on an annual basis. This is due to the fact that the storage devices are utilized only when the electrical demand is high.

To illustrate the performance of the various storage systems, sample computer output has been included for the 1000-Unit Apartment IUS. Table 22 is for the summer design day with cold storage while Table 23 presents data for the summer average day with cold storage. Both cases involve an IUS with 4 generators installed. The summer design day represents the second day of a consecutive design day run and storage is therefore partially depleted at the start of the day. For the summer average day, a full charge was assumed initially.

Tables 24 and 25 present data for a heat storage system for a winter design day and a winter average day respectively. For both cases, it is assumed that storage is initially fully charged. For the design day, energy is withdrawn from storage continually. For the winter average day, energy is initially withdrawn from storage but storage is replenished in the late afternoon hours.

Tables 26 and 27 present results of electrical storage runs for a summer design and a summer average day respectively. A round trip efficiency of 70 percent is assumed in this case with 4 generators installed. The summer design day represents the second day of a consecutive day run. Notice that the storage is not completely recharged before discharge for the next day begins. Thus, the generators are essentially running at 100 percent load at all times. For the summer average day, an initial full charge was assumed.

TABLE 22. 1000-UNIT APARTMENT DESIGN DAY COLD STORAGE PERFORMANCE

HOUR	BOILER FUEL REQD (GAL/HR)	PRIME MOVER FUEL REQD (GAL/HR)	ABSORPTION AIR COND (TONS)	COMPRESSION AIR COND (TONS)	ELECT FOR COMP A/C (KW)	GENERATOR SET OUTPUT (KW)	TOTAL H.G. HEAT RECOV (*)	WASTED HEAT (*)	ENERGY IN STORAGE (TON-HR)	NO. GEN
1 AM	0.0	145.0	223.4	958.4	942.2	1912.0	4.840	2.509	551.2	4
2 AM	0.0	139.5	223.7	980.0	961.2	1839.3	4.636	2.635	1029.2	4
3 AM	0.0	127.2	201.5	980.0	961.2	1677.3	4.185	2.453	1520.1	4
4 AM	0.0	126.9	203.0	980.0	961.2	1673.3	4.174	2.499	2039.1	4
5 AM	0.0	126.3	201.9	980.0	961.2	1655.3	4.152	2.479	2572.7	4
6 AM	0.0	125.9	192.9	980.0	961.2	1673.3	4.174	2.297	2999.3	4
7 AM	0.0	135.7	165.3	980.0	961.2	1789.0	4.495	1.550	3258.8	4
8 AM	0.0	145.0	334.0	944.2	929.7	1912.0	9.410	.151	3543.6	4
9 AM	0.0	143.0	346.2	980.0	961.2	1895.1	9.335	.439	3805.9	4
10 AM	0.0	138.4	420.5	980.0	961.2	1825.0	9.166	2.024	4044.9	4
11 AM	0.0	139.6	374.5	980.0	961.2	1841.0	9.211	1.978	4179.8	4
NOON	0.0	140.2	371.9	980.0	961.2	1843.0	9.233	1.919	4292.8	4
1 PM	0.0	139.4	419.0	950.9	944.4	1833.2	9.203	1.951	4395.6	4
2 PM	0.0	135.9	413.6	899.5	790.5	1792.4	9.075	1.940	4395.6	4
3 PM	0.0	139.8	399.7	945.5	930.9	1842.7	9.216	1.579	4395.6	4
4 PM	0.0	143.0	383.6	980.0	961.2	1895.0	9.334	1.136	4393.0	4
5 PM	0.0	145.0	409.6	810.3	712.1	1912.0	9.410	1.663	4282.8	4
6 PM	0.0	145.0	392.1	457.6	402.1	1912.0	9.410	1.312	3835.4	4
7 PM	0.0	145.0	337.1	159.5	140.1	1912.0	9.410	.213	3155.0	4
8 PM	0.0	151.5	154.2	0.0	0.0	1987.7	5.157	.950	2232.6	4
9 PM	0.0	151.5	131.0	0.0	0.0	1987.7	5.157	.487	1344.2	4
10 PM	0.0	151.5	135.3	0.0	0.0	1987.7	5.157	.571	504.4	4
11 PM	0.0	145.0	160.7	239.3	262.1	1912.0	4.840	1.255	48.3	4
MID-NT	0.0	145.0	194.1	742.2	652.2	1912.0	4.840	1.923	160.3	4
TOTAL	0.0	3371.6	5787.9	17956.5	15773.2	44422.9	157.219	36.131		

* MILLIONS OF BTU PER HOUR

TABLE 23. 1000-UNIT APARTMENT AVERAGE DAY COLD STORAGE PERFORMANCE

HOUR	BOILER FUEL REQD (GAL/HR)	PRIME MOVER FUEL REQD (GAL/HR)	ABSORPTION AIR COND (TONS)	COMPRESSION AIR COND (TONS)	ELECT FOR COMP A/C (KW)	GENERATOR SET OUTPUT (KW)	TOTAL H.G. HEAT RECOV (*)	WASTED HEAT (*)	ENERGY IN STORAGE (TON-HR)	NO. GEN
1 AM	0.0	92.9	133.7	175.9	154.6	1224.5	3.047	1.544	4395.6	3
2 AM	0.0	84.4	127.7	149.3	131.2	1109.3	2.715	1.610	4395.6	3
3 AM	0.0	70.3	109.2	126.3	111.0	927.1	2.339	1.251	4395.6	2
4 AM	0.0	68.5	107.8	103.4	90.8	902.9	2.271	1.265	4395.6	2
5 AM	0.0	67.1	105.3	91.9	80.7	884.8	2.220	1.244	4395.6	2
6 AM	0.0	72.1	104.3	157.0	137.9	950.0	2.403	1.116	4395.6	2
7 AM	0.0	87.5	83.1	256.5	225.4	1153.2	2.852	.643	4395.6	3
8 AM	0.0	94.6	208.3	188.1	165.3	1247.6	7.660	0.000	4395.6	3
9 AM	0.0	97.1	246.5	290.9	255.7	1279.6	7.768	0.000	4395.6	3
10 AM	0.0	92.5	342.4	290.9	255.7	1219.5	7.603	1.154	4395.6	3
11 AM	0.0	98.6	305.1	363.7	319.6	1299.4	7.823	.285	4395.6	3
NOON	0.0	100.2	304.2	379.0	333.0	1320.9	7.883	.232	4395.6	3
1 PM	0.0	98.8	349.5	352.2	309.5	1303.3	7.834	1.166	4395.6	3
2 PM	0.0	100.2	354.1	363.7	319.6	1321.4	7.884	1.228	4395.6	3
3 PM	0.0	103.5	339.3	402.0	353.2	1365.1	8.007	.859	4395.6	3
4 PM	0.0	106.5	322.6	432.6	380.1	1404.0	8.116	.462	4395.6	3
5 PM	0.0	117.4	359.1	395.7	347.7	1547.6	8.399	1.236	4395.6	4
6 PM	0.0	139.8	382.4	379.0	333.0	1842.9	9.216	1.233	4395.5	4
7 PM	0.0	145.0	337.1	159.5	140.1	1912.0	9.410	.213	4204.5	4
8 PM	0.0	151.5	154.2	0.0	0.0	1987.7	5.157	.950	3691.5	4
9 PM	0.0	151.5	131.0	0.0	0.0	1987.7	5.157	.487	3171.4	4
10 PM	0.0	151.5	135.3	0.0	0.0	1987.7	5.157	.571	2690.0	4
11 PM	0.0	145.0	160.7	298.3	262.1	1912.0	4.840	1.255	2715.6	4
MD-NT	0.0	145.0	194.1	742.2	652.2	1912.0	4.840	1.923	3296.2	4
TOTAL	0.0	2581.5	5397.3	6097.8	5358.4	34002.1	140.620	21.925		

* MILLIONS OF BTU PER HOUR

TABLE 24. 1000-UNIT APARTMENT DESIGN DAY HEAT STORAGE PERFORMANCE

HOUR	BOILER FUEL REQD (GAL/HR)	PRIME MOVER FUEL REQD (GAL/HR)	ABSORPTION AIR COND (TONS)	COMPRESSION AIR COND (TONS)	ELECT FOR COMP A/C (KW)	GENERATOR SET OUTPUT (KW)	TOTAL H.G. HEAT RECOV (*)	WASTED HEAT (*)	ENERGY IN STORAGE (**)	NO. GEN
1 AM	0.0	81.7	0.0	0.0	0.0	1069.8	2.591	1.343	258.099	3
2 AM	0.0	75.5	0.0	0.0	0.0	978.1	2.287	1.421	251.790	3
3 AM	0.0	61.9	0.0	0.0	0.0	816.1	2.031	1.122	244.869	2
4 AM	0.0	61.5	0.0	0.0	0.0	812.1	2.020	1.158	237.713	2
5 AM	0.0	61.0	0.0	0.0	0.0	804.1	1.998	1.148	230.276	2
6 AM	0.0	61.6	0.0	0.0	0.0	812.1	2.020	.956	222.504	2
7 AM	0.0	70.4	0.0	0.0	0.0	927.9	2.341	.219	214.160	2
8 AM	0.0	82.6	0.0	0.0	0.0	1082.3	7.200	0.000	208.178	3
9 AM	0.0	78.5	0.0	0.0	0.0	1023.9	7.016	0.000	202.576	3
10 AM	0.0	74.6	0.0	0.0	0.0	963.8	6.805	.804	199.335	3
11 AM	0.0	75.6	0.0	0.0	0.0	979.8	6.864	0.000	195.258	3
NOON	0.0	76.1	0.0	0.0	0.0	997.8	6.893	0.000	191.330	3
1 PM	0.0	76.5	0.0	0.0	0.0	993.8	6.915	.764	188.657	3
2 PM	0.0	77.0	0.0	0.0	0.0	1001.8	6.945	.817	186.285	3
3 PM	0.0	77.7	0.0	0.0	0.0	1011.8	6.977	.413	183.624	3
4 PM	0.0	78.5	0.0	0.0	0.0	1023.8	7.015	0.000	180.631	3
5 PM	0.0	91.0	0.0	0.0	0.0	1199.9	7.549	.670	178.802	3
6 PM	0.0	114.7	0.0	0.0	0.0	1509.9	8.288	.836	177.712	4
7 PM	0.0	134.4	0.0	0.0	0.0	1771.9	9.017	.052	176.539	4
8 PM	0.0	151.5	0.0	0.0	0.0	1987.7	5.157	.950	172.344	4
9 PM	0.0	151.5	0.0	0.0	0.0	1987.7	5.157	.487	167.815	4
10 PM	0.0	151.5	0.0	0.0	0.0	1987.7	5.157	.571	163.509	4
11 PM	0.0	125.1	0.0	0.0	0.0	1649.9	4.110	.950	158.661	4
MD-NT	0.0	95.6	0.0	0.0	0.0	1259.8	3.144	1.001	153.059	3
TOTAL	0.0	2185.4	0.0	0.0	0.0	28643.7	125.494	15.683		

* MILLIONS OF BTU PER HOUR

** MILLIONS OF BTU

TABLE 25. 1000-UNIT APARTMENT AVERAGE DAY HEAT STORAGE PERFORMANCE

HOUR	BOILER FUEL REQD (GAL/HR)	PRIME MOVER FUEL REQD (GAL/HR)	ABSORPTION AIR COND (TONS)	COMPRESSION AIR COND (TONS)	ELECT FOR COMP A/C (KW)	GENERATOR SET OUTPUT (KW)	TOTAL H.G. HEAT RECOV (*)	WASTED HEAT (*)	ENERGY IN STORAGE (**)	NO. GEN
1 AM	0.0	81.7	0.0	0.0	0.0	1069.8	2.591	1.343	262.290	3
2 AM	0.0	75.5	0.0	0.0	0.0	978.1	2.287	1.421	260.239	3
3 AM	0.0	61.9	0.0	0.0	0.0	816.1	2.031	1.122	257.524	2
4 AM	0.0	61.6	0.0	0.0	0.0	812.1	2.020	1.158	254.599	2
5 AM	0.0	61.0	0.0	0.0	0.0	804.1	1.998	1.148	251.363	2
6 AM	0.0	61.6	0.0	0.0	0.0	812.1	2.020	.956	247.730	2
7 AM	0.0	70.4	0.0	0.0	0.0	927.9	2.341	.219	243.412	2
8 AM	0.0	82.6	0.0	0.0	0.0	1082.3	7.200	0.000	241.830	3
9 AM	0.0	78.5	0.0	0.0	0.0	1023.9	7.016	0.000	241.271	3
10 AM	0.0	74.6	0.0	0.0	0.0	963.8	6.805	.804	243.573	3
11 AM	0.0	75.6	0.0	0.0	0.0	979.8	6.864	0.000	245.460	3
NOON	0.0	76.1	0.0	0.0	0.0	987.8	6.893	0.000	247.646	3
1 PM	0.0	76.5	0.0	0.0	0.0	993.8	6.915	.764	251.289	3
2 PM	0.0	77.0	0.0	0.0	0.0	1001.8	6.945	.817	255.336	3
3 PM	0.0	77.7	0.0	0.0	0.0	1011.8	6.977	.413	259.169	3
4 PM	0.0	78.5	0.0	0.0	0.0	1023.8	7.015	0.000	262.395	3
5 PM	0.0	91.0	0.0	0.0	0.0	1199.9	7.549	3.041	264.000	3
6 PM	0.0	114.7	0.0	0.0	0.0	1509.9	8.288	4.994	264.000	4
7 PM	0.0	134.4	0.0	0.0	0.0	1771.9	9.017	3.749	264.000	4
8 PM	0.0	151.5	0.0	0.0	0.0	1987.7	5.157	1.444	264.000	4
9 PM	0.0	151.5	0.0	0.0	0.0	1987.7	5.157	.487	263.744	4
10 PM	0.0	151.5	0.0	0.0	0.0	1987.7	5.157	.571	263.596	4
11 PM	0.0	125.1	0.0	0.0	0.0	1649.9	4.110	.950	262.938	4
MD-NT	0.0	95.6	0.0	0.0	0.0	1259.8	3.144	1.001	261.498	3
TOTAL	0.0	2186.4	0.0	0.0	0.0	28643.7	125.494	26.402		

* MILLIONS OF BTU PER HOUR

** MILLIONS OF BTU

TABLE 26. 1000-UNIT APARTMENT DESIGN SUMMER DAY ELECTRICAL STORAGE PERFORMANCE

HOUR	BOILER FUEL REQD (GAL/HR)	PRIME MOVER FUEL REQD (GAL/HR)	TOTAL FUEL REQD (GAL/HR)	ABSORPTION AIR COND (TONS)	COMPRESSION AIR COND (TONS)	ELECT FOR COMP A/C (KW)	GENERATOR SET OUTPUT (KW)	TOTAL H.G. HEAT RECOV (*)	WASTED HEAT (*)	NO. GEN
1 AM	0.0	145.0	145.0	223.4	553.0	496.0	1912.0	4.840	2.508	4
2 AM	0.0	145.0	145.0	233.9	498.4	439.0	1912.0	4.840	2.719	4
3 AM	0.0	145.0	145.0	234.2	450.9	395.3	1912.0	4.840	2.725	4
4 AM	0.0	145.0	145.0	235.3	423.3	372.0	1912.0	4.840	2.766	4
5 AM	0.0	145.0	145.0	236.3	407.5	359.2	1912.0	4.840	2.766	4
6 AM	0.0	145.0	145.0	225.2	515.7	453.2	1912.0	4.840	2.563	4
7 AM	0.0	145.0	145.0	192.6	698.9	614.1	1912.0	4.840	1.691	4
8 AM	0.0	145.0	145.0	334.0	655.0	575.6	1912.0	9.410	.151	4
9 AM	0.0	145.0	145.0	350.0	709.5	623.5	1912.0	9.410	.470	4
10 AM	0.0	145.0	145.0	432.7	724.4	636.6	1912.0	9.410	2.124	4
11 AM	0.0	145.0	145.0	394.5	830.7	730.0	1912.0	9.410	1.160	4
NOON	0.0	145.0	145.0	380.5	853.8	759.1	1912.0	9.410	1.082	4
1 PM	0.0	145.0	145.0	429.3	832.6	731.7	1912.0	9.410	2.036	4
2 PM	0.0	145.0	145.0	430.4	878.9	772.3	1912.0	9.410	2.077	4
3 PM	0.0	145.0	145.0	409.4	930.9	818.0	1912.0	9.410	1.559	4
4 PM	0.0	145.0	145.0	387.3	968.4	851.0	1912.0	9.410	1.217	4
5 PM	0.0	145.0	145.0	409.5	922.1	810.3	1912.0	9.410	1.663	4
6 PM	0.0	145.0	145.0	392.1	900.6	791.4	1912.0	9.410	1.312	4
7 PM	0.0	145.0	145.0	337.1	825.5	725.4	1912.0	9.410	.213	4
8 PM	0.0	145.0	145.0	138.4	943.9	829.3	1912.0	4.840	.808	4
9 PM	0.0	145.0	145.0	115.2	839.1	730.7	1912.0	4.840	.344	4
10 PM	0.0	145.0	145.0	113.4	851.2	743.0	1912.0	4.840	.429	4
11 PM	0.0	145.0	145.0	160.7	750.0	653.0	1912.0	4.840	1.255	4
MD-NT	0.0	145.0	145.0	194.1	625.9	549.9	1912.0	4.840	1.923	4
TOTAL	0.0	3480.3	3480.3	5975.9	17660.9	15513.5	45888.0	171.000	37.659	

HOUR	DOMESTIC ELEC DEMAND (KW)	COMPRESSION ELEC DEMAND (KW)	STORAGE ELEC DEMAND (KW)	GENERATOR SET OUTPUT (KW)	ENERGY IN STORAGE (KWH)
1 AM	1059.8	496.0	356.2	1912.0	25525.0
2 AM	979.1	439.0	496.0	1912.0	25940.0
3 AM	916.1	396.3	599.7	1912.0	26525.4
4 AM	812.1	372.0	727.9	1912.0	27134.4
5 AM	804.1	358.2	749.7	1912.0	27761.7
6 AM	812.1	453.2	646.7	1912.0	28302.8
7 AM	927.9	614.1	370.0	1912.0	28612.4
8 AM	1082.3	575.6	254.1	1912.0	28825.0
9 AM	1023.9	623.5	264.6	1912.0	29045.3
10 AM	963.9	636.6	311.6	1912.0	29307.0
11 AM	979.8	730.0	202.2	1912.0	29475.2
NOON	987.8	759.1	165.1	1912.0	29614.3
1 PM	993.8	731.7	186.5	1912.0	29773.3
2 PM	1001.8	772.3	137.9	1912.0	29885.7
3 PM	1011.8	818.0	82.2	1912.0	29954.4
4 PM	1023.8	851.0	37.1	1912.0	29985.5
5 PM	1199.3	810.3	-98.2	1912.0	29868.1
6 PM	1509.9	791.4	-389.3	1912.0	29402.9
7 PM	1771.9	725.4	-585.3	1912.0	28703.3
8 PM	1987.7	829.3	-905.0	1912.0	27621.5
9 PM	1987.7	730.7	-966.4	1912.0	26535.0
10 PM	1987.7	743.0	-823.7	1912.0	25601.4
11 PM	1549.9	653.0	-395.9	1912.0	25127.0
MD-NT	1259.9	549.9	102.2	1912.0	25212.5

TABLE 27. 1000-UNIT APARTMENT AVERAGE SUMMER DAY ELECTRICAL STORAGE PERFORMANCE

HOUR	BOILER FUEL REQD (GAL/HR)	PRIME MOVER FUEL REQD (GAL/HR)	TOTAL FUEL REQD (GAL/HR)	ABSORPTION AIR COND (TONS)	COMPRESSION AIR COND (TONS)	ELECT FOR COMP A/C (KW)	GENERATOR SET OUTPUT (KW)	TOTAL H.G. HEAT RECOV (*)	WASTED HEAT (*)	NO. GEN
1 AM	0.0	92.8	92.8	133.6	176.6	155.2	1223.7	3.045	1.543	3
2 AM	0.0	84.2	84.2	127.1	145.0	127.4	1105.8	2.704	1.605	3
3 AM	0.0	69.8	69.8	108.3	120.9	106.2	920.5	2.321	1.244	2
4 AM	0.0	68.1	68.1	107.2	99.9	87.8	898.4	2.258	1.259	2
5 AM	0.0	66.7	66.7	104.6	87.8	77.1	879.9	2.207	1.238	2
6 AM	0.0	71.7	71.7	103.7	153.2	134.7	945.7	2.391	1.111	2
7 AM	0.0	87.1	87.1	82.5	252.9	222.2	1148.5	2.838	.637	3
8 AM	0.0	94.3	94.3	207.5	182.7	160.6	1243.5	7.669	0.000	3
9 AM	0.0	96.9	96.9	246.1	287.8	252.9	1277.4	7.762	0.000	3
10 AM	0.0	92.2	92.2	341.9	288.4	253.4	1216.0	7.593	1.150	3
11 AM	0.0	98.1	98.1	304.3	358.7	315.2	1293.9	7.807	.279	3
NOON	0.0	99.8	99.8	303.5	373.9	328.5	1315.2	7.867	.225	3
1 PM	0.0	98.5	98.5	348.8	347.7	305.6	1298.2	7.819	1.160	3
2 PM	0.0	100.0	100.0	353.7	351.6	317.8	1318.5	7.876	1.224	3
3 PM	0.0	103.1	103.1	338.5	336.6	348.5	1359.3	7.991	.853	3
4 PM	0.0	106.3	106.3	322.2	430.3	378.1	1401.0	8.107	.459	3
5 PM	0.0	117.1	117.1	358.6	392.3	344.7	1543.9	8.389	1.232	4
6 PM	0.0	139.6	139.6	382.0	374.3	328.9	1840.0	9.208	1.229	4
7 PM	0.0	145.0	145.0	337.1	346.1	304.2	1912.0	9.410	.213	4
8 PM	0.0	145.0	145.0	138.4	524.5	460.9	1912.0	4.840	.508	4
9 PM	0.0	145.0	145.0	115.2	531.6	467.1	1912.0	4.840	.344	4
10 PM	0.0	145.0	145.0	119.4	492.8	433.0	1912.0	4.840	.429	4
11 PM	0.0	145.0	145.0	160.7	269.3	235.8	1912.0	4.840	1.255	4
MD-NT	0.0	145.0	145.0	194.1	157.2	138.1	1912.0	4.840	1.923	4
TOTAL	0.0	2556.4	2556.4	5339.1	7150.9	6283.9	33701.3	139.463	21.419	

HOUR	DOMESTIC ELEC DEMAND (KW)	COMPRESSION ELEC DEMAND (KW)	STORAGE ELEC DEMAND (KW)	GENERATOR SET OUTPUT (KW)	ENERGY IN STORAGE (KWH)
1 AM	1069.8	155.2	0.0	1223.7	30000.0
2 AM	978.1	127.4	0.0	1105.8	30000.0
3 AM	816.1	106.2	0.0	920.5	30000.0
4 AM	812.1	87.8	0.0	898.4	30000.0
5 AM	804.1	77.1	0.0	879.9	30000.0
6 AM	812.1	134.7	0.0	945.7	30000.0
7 AM	927.9	222.2	0.0	1148.5	30000.0
8 AM	1082.3	160.6	0.0	1243.5	30000.0
9 AM	1023.9	252.9	0.0	1277.4	30000.0
10 AM	963.8	253.4	0.0	1216.0	30000.0
11 AM	979.8	315.2	0.0	1293.9	30000.0
NOON	987.8	328.5	0.0	1315.2	30000.0
1 PM	993.8	305.6	0.0	1298.2	30000.0
2 PM	1001.8	317.8	0.0	1318.5	30000.0
3 PM	1011.8	348.5	0.0	1359.3	30000.0
4 PM	1023.8	378.1	0.0	1401.0	30000.0
5 PM	1199.9	344.7	0.0	1543.9	30000.0
6 PM	1509.9	329.9	0.0	1840.0	30000.0
7 PM	1771.9	304.2	-164.1	1912.0	29833.9
8 PM	1987.7	460.9	-536.6	1912.0	29162.6
9 PM	1987.7	467.1	-542.8	1912.0	28513.8
10 PM	1987.7	433.0	-508.7	1912.0	27305.8
11 PM	1649.9	235.8	26.4	1912.0	27927.8
MD-NT	1259.8	138.1	514.1	1912.0	28357.9

COMPARISON OF ENERGY STORAGE CONCEPTS AND SELECTION OF PRIMARY CANDIDATES

The energy storage concepts which were addressed in this study were classified into six categories for the purposes of assessing technical and cost characteristics. These categories were:

- Inertial Energy Storage
- Superconducting Magnetic Energy Storage
- Electrochemical Energy Storage
- Chemical Energy Storage
- Compressed Air Energy Storage
- Thermal Energy Storage.

A seventh category, pumped hydroelectric storage, was not treated in this study since it was felt that the special siting requirements for these systems would be too restrictive for widespread IUS application.

The assessments of energy storage concepts in each of the energy storage categories were carried out by study team members who were knowledgable in the areas of technology appropriate to each category. The assessment procedure which was followed for each category can be summarized in stepwise fashion as follows:

(1) Identification of candidate energy storage concepts or alternative implementations in each category based on a review of the literature as well as discussions with contacts in the energy storage field.

(2) Preliminary assessment of each of the identified concepts to select those which appear to be most applicable to IUS.

(3) Generation of the technical and cost characteristics of the concepts selected.

The technical and cost characteristics for each of the energy storage concepts were developed based primarily on information drawn from the literature supplemented by discussions with equipment manufacturers and researchers.

The details of the assessments in each of the energy storage categories are presented in Volume III of this report. Results of these assessments are briefly summarized below.

Inertial Energy Storage

Inertial (i.e., flywheel) energy storage (IES) systems store mechanical energy as a rotating mass. A feasible inertial storage system must, in addition to the wheel itself, include equipment to effect the transfer of energy between the IUS bus bar and the flywheel (power conditioning, a motor/generator, and a coupling/gearbox) as well as appropriate bearings, vacuum enclosures, and seals/feedthroughs. This assessment task has resulted in the identification and evaluation of alternatives for each of these components and a conceptual design of a near-term inertial energy storage system applicable to IUS has evolved. Technical and cost characteristics of the preferred design were developed for comparison with other energy storage concepts.

The conceptual inertial storage system design which was identified consists of a modular arrangement with a gang of several wheels connected to a common transmission and generator. The wheels are mounted with a horizontal spin-axis and are located in underground vaults for safety purposes. The wheel design selected consists of a multi-rim design utilizing composite materials (fiberglass or kevlar). The near-term system must use ball or roller bearings which, unfortunately, will require replacement at about one-year intervals--at a considerable expense. Advanced bearing systems offer the potential for increasing the overhaul period by a factor of 10, but are not likely to be available for near-term systems.

The calculations of net relative costs of near-term inertial storage systems are summarized in Tables 28 and 29 for the 1000-Unit Apartment and the Village Complex respectively. The data in both these tables were developed based on replacement of a single generator set. In addition, the cost estimates used correspond to the low end of the range reported in Volume III. Thus the net relative costs calculated should be viewed as optimistic estimates.

TABLE 28. NET RELATIVE COST OF AN INERTIAL STORAGE SYSTEM INSTALLED IN THE 1000-UNIT APARTMENT IUS

Item	Cost, Thousands of Dollars	Cost Discounted to Installation Date, Thousands of Dollars			
		Case[(a)] A	Case[(a)] B	Case[(a)] C	Case[(a)] D
Installed Cost of Storage System	280				
Credit for Generators Replaced[(b)]	-108				
Credit for Boilers Replaced	0				
Net First Cost of Storage	172	172	172	172	172
Net Annual Fuel Cost	0/yr				
Net O&M Costs	16/yr	163	100	163	100
Life Cycle Cost of Storage System		335	272	335	272
Life Cycle Cost of "No Storage" Option		8960	6710	10,850	7,560
Net Relative Cost		1.037	1.041	1.031	1.036
Score		1	1	2	1

(a) Case A - 7-1/2 percent per year discount rate, no fuel escalation.
Case B - 15 percent per year discount rate, no fuel escalation.
Case C - 7-1/2 percent per year discount rate, 5 percent per year fuel escalation.
Case D - 15 percent per year discount rate, 5 percent per year fuel escalation.

(b) One generator set replaced.

TABLE 29. NET RELATIVE COST OF AN INERTIAL STORAGE SYSTEM INSTALLED IN THE VILLAGE COMPLEX IUS

Item	Cost, Thousands of Dollars	Cost Discounted to Installation Date, Thousands of Dollars			
		Case[(a)] A	Case[(a)] B	Case[(a)] C	Case[(a)] D
Installed Cost of Storage System	1124				
Credit for Generators Replaced[(b)]	-768				
Net First Cost of Storage	356	356	356	356	356
Net Annual Fuel Costs	0				
Net O&M Costs	49/yr	499	306	499	306
Life Cycle Cost of Storage System		855	662	855	662
Life Cycle Cost of "No Storage" Options		62,300	53,600	66,800	55,800
Net Relative Cost		1.014	1.012	1.013	1.012
Score		4	4	4	4

(a) Case A - 7-1/2 percent per year discount rate, no fuel escalation.
Case B - 15 percent per year discount rate, no fuel escalation.
Case C - 7-1/2 percent per year discount rate, 5 percent per year fuel escalation.
Case D - 15 percent per year discount rate, 5 percent per year fuel escalation.

(b) One generator set replaced.

A major cost item for near-term flywheel storage systems will be the frequent replacement of bearings. It was therefore desirable to assess the cost savings which could be realized if advanced bearing systems could be developed. The net relative cost for advanced bearing flywheel systems is shown in Table 30 for the 1000-Unit Apartment. While the net relative cost is reduced for the advanced system, it is apparent that the improvement is not sufficient to make flywheel storage systems competitive with the no-storage baseline.

Superconducting Magnetic Energy Storage

The essence of a superconducting magnetic energy storage system (SMES) is a superconducting magnet which is an electromagnet wound with conductors containing zero resistance components capable of sustaining the desired conductor currents under the operational conditions so that no ohmic loss is experienced in steady state current operation. SMES could be relatively compact and efficient as the energy is stored directly as electromagnetic energy.

As in the inertial energy storage assessment, technical and cost characteristics of SMES systems were developed based on a conceptual design which appeared to be applicable to IUS. The device consists of a solenoidal coil configuration with cold reinforcement. It should be pointed out that SMES systems of the size under consideration have not been built and a significant amount of research and development is required before these systems may be implemented. Cost projections indicate that these systems are better suited to much larger energy storage capacities than are required for IUS and they do not appear to be cost competitive with other energy storage concepts for this application. Tables 31 and 32 summarize the calculation of net relative cost for SMES systems as applied to the 1000-Unit Apartment and the Village Complex respectively. Both tables correspond to the replacement of one generator set which represents the most favorable case for SMES.

TABLE 30. NET RELATIVE COST OF AN ADVANCED INERTIAL STORAGE SYSTEM INSTALLED IN THE 1000-UNIT APARTMENT IUS

Item	Cost, Thousands of Dollars	Cost Discounted to Installation Date, Thousands of Dollars			
		Case[a] A	Case[a] B	Case[a] C	Case[a] D
Installed Cost of Storage System	280				
Credit for Generators Replaced[b]	-108				
Credit for Boilers Replaced	0				
Net First Cost of Storage	172	172	172	172	172
Net Annual Fuel Costs	0				
Net O&M Costs	16/10 yr	7.8	4.0	7.8	4.0
Life Cycle Cost of Storage System		180	176	180	176
Life Cycle Cost of "No Storage" Options		8960	6710	10,850	7560
Net Relative Cost		1.020	1.026	1.017	1.023
Score		3	2	3	3

(a) Case A - 7-1/2 percent per year discount rate, no fuel escalation.
Case B - 15 percent per year discount rate, no fuel escalation.
Case C - 7-1/2 percent per year discount rate, 5 percent per year fuel escalation.
Case D - 15 percent per year discount rate, 5 percent per year fuel escalation.

(b) One generator set replaced.

TABLE 31. NET RELATIVE COST OF AN SMES STORAGE SYSTEM INSTALLED IN 1000-UNIT APARTMENT IUS

Item	Cost, Thousands of Dollars	Cost Discounted to Installation Date, Thousands of Dollars			
		Case[a] A	Case[a] B	Case[a] C	Case[a] D
Installed Cost of Storage System	1130				
Credit for Generator Sets Replaced[b]	-108				
Net First Cost	1022	1022	1022	1022	1022
Annual Fuel Savings	~ 0/yr	0	0	0	0
Net O&M Costs	~ 0	0	0	0	0
Discounted Life Cycle Cost of Storage System		1022	1022	1022	1022
Discounted Life Cycle Cost of "No Storage" Baseline		8960	6710	10,850	7560
Net Relative Cost		1.114	1.152	1.094	1.135
Score		1	1	1	1

(a) Case A - 7-1/2 percent per year discount rate, no fuel escalation.
Case B - 15 percent per year discount rate, no fuel escalation.
Case C - 7-1/2 percent per year discount rate, 5 percent per year fuel escalation.
Case D - 15 percent per year discount rate, 5 percent per year fuel escalation.

(b) One generator set replaced.

TABLE 32. NET RELATIVE COST OF AN SMES STORAGE SYSTEM INSTALLED IN THE VILLAGE COMPLEX IUS

Item	Cost, Thousands of Dollars	Cost Discounted to Installation Date, Thousands of Dollars			
		Case[(a)] A	Case[(a)] B	Case[(a)] C	Case[(a)] D
Installed Cost of Storage System	2550				
Credit for Generator Sets Replaced[(b)]	-768				
Net First Cost	1782	1782	1782	1782	1782
Annual Fuel Savings	0				
Net Annual O&M Costs	0				
Discounted Life Cycle Cost of Storage		1782	1782	1782	1782
Discounted Life Cycle Cost of "No Storage" Baseline		62,300	53,600	66,800	55,800
Net Relative		1.029	1.033	1.027	1.032
Score		2	2	2	2

(a) Case A - 7-1/2 percent per year discount rate, no fuel escalation.
Case B - 15 percent per year discount rate, no fuel escalation.
Case C - 7-1/2 percent per year discount rate, 5 percent per year fuel escalation.
Case D - 15 percent per year discount rate, 5 percent per year fuel escalation.

(b) One generator set replaced.

TABLE 33. NET RELATIVE COST OF LEAD DIOXIDE-LEAD BATTERY STORAGE SYSTEM INSTALLED IN THE 1000-UNIT APARTMENT IUS

Item	Cost, Thousands of Dollars	Cost Discounted to Installation Date, Thousands of Dollars			
		Case[(a)] A	Case[(a)] B	Case[(a)] C	Case[(a)] D
Installed Cost	163				
Credit for Gen Set Replacement[(b)]	-108				
Net First Cost	55	55	55	55	55
Annual Fuel Savings	0				
Replacement Costs (5-yr intervals)					
at 5 yr	71	49	35	49	35
at 10 yr	50	24	12	24	12
at 15 yr	43	15	5	15	5
Life Cycle Costs		143	107	143	107
Life Cycle Cost of "No Storage" Baseline		8960	6710	10,850	7560
Net Relative Cost		1.016	1.016	1.013	1.014
Score		3	3	4	4

(a) Case A - 7-1/2 percent per year discount rate, no fuel escalation.
Case B - 15 percent per year discount rate, no fuel escalation.
Case C - 7-1/2 percent per year discount rate, 5 percent per year fuel escalation.
Case D - 15 percent per year discount rate, 5 percent per year fuel escalation.

(b) One generator set replaced.

Electrochemical Energy Storage

Electrochemical storage installations for IUS application would consist of (1) power conditioning equipment and (2) rechargeable batteries arrayed as the energy storage device. Four electrochemical storage systems were selected for assessment. They are (1) lead dioxide-lead (or lead-acid), (2) zinc-chlorine hydrate, (3) lithium-metal sulfide, and (4) sodium-sulfur systems. Of these, only the lead dioxide-lead systems are available for near-term applications. Tables 33 and 34 summarize the calculations for net relative cost of near-term PbO_2/Pb battery systems applied to the 1000-Unit Apartment and the Village Complex respectively. It is appropriate to note that, for battery systems, replacement at approximately 5 year intervals is required. The replacement costs are included in the calculation of NRC. Scores of 4 and 5 have been assigned to the 1000-Unit Apartment and the Village Complex, respectively.

It is apparent that the near term lead acid battery systems will not be cost competitive for IUS application. It is appropriate, however, to estimate the economic profitability of advanced battery systems. Table 35 gives estimates of the net relative cost of sodium-sulfer battery systems applied to the Village Complex. From the results of the calculations, it would appear that these advanced battery systems will result in a slight reduction in the life cycle cost of IUS installations over the no-storage baseline.

Chemical Energy Storage

In the electrochemical energy storage devices discussed in the previous section, energy was fed into an energy converter, namely the battery, in which the chemical states of the reactants were changed. These "active" materials were then stored within the battery until it was necessary to recover the energy. The reactants then reverted to their previous state. Electrochemical energy storage is thus a special case of chemical energy storage in which (1) electrical energy is stored and released, and (2) the energy converter is also the energy store.

TABLE 34. NET RELATIVE COST OF LEAD DIOXIDE-LEAD BATTERY STORAGE SYSTEM INSTALLED IN THE VILLAGE COMPLEX IUS

Item	Cost, Thousands of Dollars	Cost Discounted to Installation Date, Thousands of Dollars			
		Case[(a)] A	Case[(a)] B	Case[(a)] C	Case[(a)] D
Installed Cost	698				
Credit for Generator Replacement[(b)]	-768				
Net First Cost	- 70				
Annual Fuel Savings	0	-70	-70	-70	-70
Replacement Costs (5-yr intervals)					
at 5 yr	212	147	105	147	105
at 10 yr	152	74	37	74	37
at 15 yr	129	44	16	44	16
Life Cycle Costs		195	88	195	88
Life Cycle Cost of "No Storage" Baseline		62,300	53,600	66,800	55,800
Net Relative Cost		1,003	1,002	1,003	1,002
Score		5	5	5	5

(a) Case A - 7-1/2 percent per year discount rate, no fuel escalation.
Case B - 15 percent per year discount rate, no fuel escalation.
Case C - 7-1/2 percent per year discount rate, 5 percent per year fuel escalation.
Case D - 15 percent per year discount rate, 5 percent per year fuel escalation.

(b) One generator set replaced.

TABLE 35. NET RELATIVE COST OF A SODIUM-SULFUR BATTERY STORAGE SYSTEM INSTALLED IN THE VILLAGE COMPLEX IUS

Item	Cost, Thousands of Dollars	Cost Discounted to Installation Date, Thousands of Dollars			
		Case[(a)] A	Case[(a)] B	Case[(a)] C	Case[(a)] D
Installed Cost of Storage System	368				
Credit for Generators Replaced[(b)]	-768				
Credit for Boilers Replaced	0				
Net First Cost of Storage	-400	-400	-400	-400	-400
Net Annual Fuel Costs	0	0	0	0	0
Net O&M Costs (Replacement at 5-yr intervals)		101	58	101	58
Life Cycle Cost of Storage System		-299	-342	-299	-342
Life Cycle Cost of "No Storage" Options		62,300	53,600	66,800	55,800
Net Relative Cost		0.995	0.994	0.996	0.994
Score		6	6	5	6

(a) Case A - 7-1/2 percent per year discount rate, no fuel escalation.
Case B - 15 percent per year discount rate, no fuel escalation.
Case C - 7-1/2 percent per year discount rate, 5 percent per year fuel escalation.
Case D - 15 percent per year discount rate, 5 percent per year fuel escalation.

(b) One generator set replaced.

Chemical energy storage devices utilize electrical energy for the production of a fuel (e.g., hydrogen). The fuel is stored until the storage system is called upon to produce power and the fuel is reconverted to electrical energy. While the overall process is recognized to possess low efficiency, chemical storage concepts were examined in order to assess the possibilities of attractive cost characteristics.

The assessment of chemical energy storage systems concentrated on the three subsystems required; (1) production, (2) storage, and (3) convertion. A near-term configuration was identified which consisted of a water electrolyzer for the production of hydrogen, a high pressure steel tank storage system, and a fuel cell conversion system. Calculation of the net relative cost for the near term chemical storage systems are summarized in Tables 36 and 37 for the 1000-Unit Apartment and the Village Complex respectively. The estimates are based on the replacement of one generator set for each application.

Compressed Air Storage

The compressed air storage concept is a functional modification of the open-cycle combustion gas turbine which involves the separation of the compressor from the remainder of the gas turbine cycle. Off-peak electrical energy is utilized to operate the compressor and the compressed air is stored. The stored compressed air is then utilized at a later time allowing the turbine portion of the gas turbine cycle to utilize essentially all of its shaft power for the production of electrical power.

The assessment of compressed air storage technology which was carried out in this study has resulted in the selection of a hard rock storage cavern as the preferred storage concept for near term application to IUS. The net relative costs for this preferred compressed air storage system are summarized in Tables 38 and 39 for the 1000-Unit Apartment and the Village Complex, respectively. Both tables refer to the replacement of one of the diesel generator sets. It should be pointed out that, for the case of replacement of more than one generator set, the economics of compressed air storage becomes less favorable due to the increase in the storage volume required.

TABLE 36. NET RELATIVE COST OF A CHEMICAL STORAGE SYSTEM INSTALLED IN THE 1000-UNIT APARTMENT IUS

Item	Cost, Thousands of Dollars	Cost Discounted to Installation Date, Thousands of Dollars			
		Case[a] A	Case[a] B	Case[a] C	Case[a] D
Installed Cost of Storage System	417				
Credit for Generator Sets Replaced[b]	-108				
Net First Cost	309				
Life Cycle Cost		309	309	309	309
Life Cycle Cost of "No Storage" Option		8960	6710	10,850	7560
Net Relative Cost		1.034	1.046	1.028	1.041
Score		2	1	2	1

(a) Case A - 7-1/2 percent per year discount rate, no fuel escalation.
Case B - 15 percent per year discount rate, no fuel escalation.
Case C - 7-1/2 percent per year discount rate, 5 percent per year fuel escalation.
Case D - 15 percent per year discount rate, 5 percent per year fuel escalation.

(b) One generator set replaced.

TABLE 37. NET RELATIVE COST OF A CHEMICAL STORAGE SYSTEM INSTALLED IN THE VILLAGE COMPLEX IUS

Item	Cost, Thousands of Dollars	Cost Discounted to Installation Date, Thousands of Dollars			
		Case[a] A	Case[a] B	Case[a] C	Case[a] D
Installed Cost of Storage System	3014				
Credit for Generator Set Replaced[b]	-768				
Net First Cost	2246	2246	2246	2246	2246
Annual Fuel Savings	0				
Life Cycle Cost		2246	2246	2246	2246
Life Cycle Cost of "No Storage" Alternative		62,300	53,600	66,800	55,800
Net Relative Cost		1.036	1.042	1.034	1.040
Score		1	1	2	1

(a) Case A - 7-1/2 percent per year discount rate, no fuel escalation.
Case B - 15 percent per year discount rate, no fuel escalation.
Case C - 7-1/2 percent per year discount rate, 5 percent per year fuel escalation.
Case D - 15 percent per year discount rate, 5 percent per year fuel escalation.

(b) One generator set replaced.

TABLE 38. NET RELATIVE COST OF A COMPRESSED AIR STORAGE SYSTEM INSTALLED IN THE 1000-UNIT APARTMENT IUS

Item	Cost, Thousands of Dollars	Cost Discounted to Installation Date, Thousands of Dollars			
		Case[a] A	Case[a] B	Case[a] C	Case[a] D
Installed Cost of Storage System	122				
Credit for Generators Replaced[b]	-108				
Credit for Boilers Replaced	0				
Net First Cost of Storage	14				
Net Annual Fuel Costs	~ 0				
Net O&M Costs	~ 0				
Life Cycle Cost of Storage System		14	14	14	14
Life Cycle Cost of "No Storage" Options		8960	6710	10,850	7560
Net Relative Cost		1.001	1.002	1.001	1.001
Score		5	5	5	5

(a) Case A - 7-1/2 percent per year discount rate, no fuel escalation.
Case B - 15 percent per year discount rate, no fuel escalation.
Case C - 7-1/2 percent per year discount rate, 5 percent per year fuel escalation.
Case D - 15 percent per year discount rate, 5 percent per year fuel escalation.

(b) One generator replaced.

TABLE 39. NET RELATIVE COST OF A COMPRESSED AIR STORAGE SYSTEM INSTALLED IN THE VILLAGE COMPLEX IUS

Item	Cost, Thousands of Dollars	Cost Discounted to Installation Date, Thousands of Dollars			
		Case[a] A	Case[a] B	Case[a] C	Case[a] D
Installed Cost of Storage System	651				
Credit for Generators Replaced[b]	-768				
Credit for Boilers Replaced	0				
Net First Cost of Storage	-117	-117	-117	-117	-117
Net Annual Fuel Costs	~ 0				
Net O&M Costs	~ 0				
Life Cycle Cost of Storage System		-117	-117	-117	-117
Life Cycle Cost of "No Storage" Options		62,300	53,600	66,800	55,800
Net Relative Cost		0.998	0.998	0.998	0.998
Score		5	5	5	5

(a) Case A - 7-1/2 percent per year discount rate, no fuel escalation.
Case B - 15 percent per year discount rate, no fuel escalation.
Case C - 7-1/2 percent per year discount rate, 5 percent per year fuel escalation.
Case D - 15 percent per year discount rate, 5 percent per year fuel escalation.

(b) One generator replaced.

Thermal Energy Storage

Thermal energy storage systems may be defined, for the purposes of this study, as storage systems which are charged and discharged via the transport of thermal energy across the storage system boundaries. This definition includes both the heat and cold integration concepts discussed in earlier sections of this report. The actual energy content of a thermal storage system may manifest itself as a change in the temperature of a material, as a change in the physical state of a material, or as a change in the chemical composition of a system. Thermal energy storage (TES) systems may be viewed as consisting of a thermal storage material, a vessel for containing the TES material, and a means for transporting thermal energy to and from storage. A fourth area for consideration is the method of integrating the thermal store within the IUS.

During the course of the assessment task, four thermal storage concepts were identified which appeared to be particularly applicable to IUS. These were water storage, annual cycle ice storage, thermal wells, and a paraffin-water "hybrid" system. These concepts will be discussed briefly in the following paragraphs.

Water Storage

Water storage systems appear to be particularly well suited to IUS application. Water can be used to distribute thermal energy throughout the complex or community being served thus simplifying the integration of the thermal storage system with the IUS. Moreover, water is readily available and inexpensive and a considerable amount of engineering experience exists on its use. Water storage systems have the additional advantage of being able to store chilled water during the summer months as well as heat during the winter.

The water storage system utilizes the sensible heat of water to store thermal energy. The water is contained in a tank which operates at atmospheric pressure, thus limiting the maximum temperature of operation to about 367 K (200 F). Due to the large storage volume which will be required for IUS water storage systems, it is desirable to locate the storage tank underground, with concrete being the preferred tank material.

Annual Cycle Ice Storage

Recent studies carried out at Oak Ridge National Laboratories have revived interest in a concept which utilizes ice for the storage of energy on a seasonal basis. The concept is known as Annual Cycle Energy Storage (ACES) and is normally envisioned as a means of reducing the energy requirements of residences or commercial buildings which are serviced by conventional utilities. A variation of the ACES concept which would be applicable to Integrated Utility Systems utilizes a heat pump to supply auxiliary heating requirements normally satisfied by auxiliary boilers. The heat pump evaporator withdraws energy from a specially constructed water tank, causing the temperature of the tank to drop until the water begins freezing. The freezing process continues throughout the heating seasons so that a considerable amount of ice will accumulate. The ice is stored until the summer months when it is used to supply a portion of the cooling requirements of the IUS community.

Thermal Wells

The thermal well storage concept involves the injection of pressurized hot water into an aquifer. The injected water will be less dense than the native groundwater due to its higher temperature, and will displace the colder water downward. The hot water/hot porus rock combination acts as a thermal storage medium which can be discharged by reversing the flow of water from the well.

The thermal well concept is viewed as a means of storing energy on a seasonal basis. The storage would be utilized to accept otherwise unusable high-grade heat during the fall and spring seasons when heating and cooling loads are low. This heat could then be recovered during the winter months to supply the auxiliary heating requirements of the IUS. It should be pointed out that the thermal well concept would act only as a heat storage system and would not enable the replacement of generator capacity required to meet peak cooling loads.

Paraffin Storage

The paraffin storage concept can be considered to be a hybrid system combining a paraffin storage material with a water storage system. The paraffin would be sealed in suitable containers and these containers would be placed inside a water storage tank. During winter operation, the temperature of the storage tank will be maintained above the melting temperature of the paraffin at all times and the system will operate exactly the same as a "conventional" water storage system. During the summer months the tank will be used to store chilled water and at the fully charged condition, its temperature will be 280 K (45 F) which is below the freezing point of the paraffin. As the storage system is called upon to supply cooling, the temperature of the water in the tank will rise and the phase change material will begin to melt thereby absorbing its latent heat of fusion from the water. The net effect is an apparent increase in the specific heat of the water contained in storage. Since the chilled water storage requirement normally dictates the size of a water storage tank for IUS applications, the paraffin storage system offers the possibility of substantial reduction in the volume of the storage system.

Comparison of Alternative Thermal Storage Concepts

The results of the assessment of alternative thermal storage concepts reveal that the water storage concept is superior to the other thermal concepts investigated. Water storage appears to be particularly attractive due to the relatively well developed technology available for utilizing this system. In addition, the energy savings associated with water storage systems are equal to or greater than any of the other storage concepts.

The primary advantage of water storage systems, however, is economic. Tables 40 through 43 summarize the calculation of net relative cost for each of the concepts as applied to the 1000-Unit Apartment. Water storage scores consistantly higher than the other concepts for all of the economic cases examined. This is primarily due to the combined advantage of significant energy savings as well as savings in first cost due to the replacement of generator capacity.

TABLE 40. NET RELATIVE COST OF A WATER STORAGE SYSTEM INSTALLED IN THE 1000-UNIT APARTMENT IUS

Item	Cost, Thousands of Dollars	Cost Discounted to Installation Date, Thousands of Dollars Case[a] A	Case[a] B	Case[a] C	Case[a] D
Installed Cost of Storage System	154				
Credit for Generator Sets Replaced[b]	-216				
Credit for Auxiliary Boiler Replaced	- 48				
Net First Costs	-110	-110	-110	-110	-110
Annual Fuel Savings	-7.2/yr	- 74	- 45	-108	- 60
Net O&M Costs	0/yr	0	0	0	0
Discounted Life Cycle Cost of Storage System		-184	-155	-218	-170
Discounted Life Cycle Cost of "No Storage Baseline		8960	6710	10,850	7560
Net Relative Cost		0.979	0.977	0.980	0.977
Score		7	7	7	7

(a) Case A - 7-1/2 percent per year discount rate, no fuel escalation.
Case B - 15 percent per year discount rate, no fuel escalation.
Case C - 7-1/2 percent per year discount rate, 5 percent per year fuel escalation.
Case D - 15 percent per year discount rate, 5 percent per year fuel escalation.

(b) Two generator sets replaced.

TABLE 41. NET RELATIVE COST OF ANNUAL CYCLE ICE STORAGE SYSTEM INSTALLED IN THE 1000-UNIT APARTMENT IUS

Item	Cost, Thousands of Dollars	Cost Discounted to Installation Date, Thousands of Dollars Case[a] A	Case[a] B	Case[a] C	Case[a] D
Installed Cost of Ice Storage System	460				
Credit for Generator Sets Replaced[b]	-108				
Credit for Boilers Replaced	- 48				
Net First Cost	304	304	304	304	304
Annual Fuel Savings	-5.6/yr	-57	-35	-84	-47
Life Cycle Cost of Storage System		247	269	220	257
Life Cycle Cost of "No Storage" Option		8960	6710	10,850	7560
Net Relative Cost		1.028	1.040	1.020	1.034
Score		2	1	3	2

(a) Case A - 7-1/2 percent per year discount rate, no fuel escalation.
Case B - 15 percent per year discount rate, no fuel escalation.
Case C - 7-1/2 percent per year discount rate, 5 percent per year fuel escalation.
Case D - 15 percent per year discount rate, 5 percent per year fuel escalation.

(b) One generator set replaced.

TABLE 42. NET RELATIVE COST OF A THERMAL WELL STORAGE SYSTEM INSTALLED IN THE 1000-UNIT APARTMENT INTEGRATED UTILITY SYSTEM IUS

Item	Cost, Thousands of Dollars	Cost Discounted to Installation Date, Thousands of Dollars Case[a] A	Case[a] B	Case[a] C	Case[a] D
Installed Cost of Storage	-100				
Credit for Auxiliary Boiler Replaced	-48				
Net First Cost[b]	52	52	52	52	52
Annual Fuel Savings	-7.2/yr	-74	-45	-108	-60
Life Cycle Cost of Storage System		-22	7	-56	-8
Life Cycle Cost of "No Storage" System		8960	6710	10,850	7560
Net Relative Cost		0.997	1.001	0.995	0.999
Score		5	5	6	5

(a) Case A - 7-1/2 percent per year discount rate, no fuel escalation.
Case B - 15 percent per year discount rate, no fuel escalation.
Case C - 7-1/2 percent per year discount rate, 5 percent per year fuel escalation.
Case D - 15 percent per year discount rate, 5 percent per year fuel escalation.

(b) Concept does not allow replacement of generator sets.

TABLE 43. NET RELATIVE COST OF PARAFFIN STORAGE SYSTEM INSTALLED IN 1000-UNIT APARTMENT INTEGRATED UTILITY SYSTEM

Item	Cost, Thousands of Dollars	Cost Discounted to Installation Date, Thousands of Dollars Case[a] A	Case[a] B	Case[a] C	Case[a] D
Installed Cost of Storage	297				
Credit for Generator Sets Replaced[b]	-216				
Credit for Auxiliary Boiler Replaced	-48				
Net First Cost	-33	33	33	33	33
Annual Fuel Savings	-7.2/yr	-74	-45	-108	-60
Life Cycle Cost of Storage System		-41	-12	-75	-27
Life Cycle Cost of "No-Storage" Option		8960	6710	10,850	7560
Net Relative Cost		0.995	0.998	0.993	0.996
Score		6	5	6	5

(a) Case A - 7-1/2 percent per year discount rate, no fuel escalation.
Case B - 15 percent per year discount rate, no fuel escalation.
Case C - 7-1/2 percent per year discount rate, 5 percent per year fuel escalation.
Case D - 15 percent per year discount rate, 5 percent per year fule escalation.

(b) Two generator sets replaced.

Of the remaining concepts, the paraffin system offers the potential for reducing the size of the storage tank required but the cost of this system appears to be excessive unless low cost paraffin containers can be developed.

Selection of Primary Candidate

The results of the assessment tasks were utilized to arrive at the selection of water storage as the primary candidate for near-term application to IUS. The rationale for this selection can be demonstrated by reference to Tables 44 and 45 which summarize the scoring for each of the energy storage categories.

As indicated by the scores for the net relative cost criteria, water storage is the only storage concept examined which exhibits significant dollar savings on a life cycle basis. The scoring scale for this criteria was based on increments of 1 percent. A score of 6 for net relative cost would therefore indicate a savings of about 1 percent of the life cycle cost of the no-storage baseline IUS. A score of 4 indicates that the IUS with energy storage costs 1 percent more than a no-storage IUS. Water storage systems can therefore be expected to reduce the life cycle cost of IUS installations by approximately 2 percent.

Water storage systems also scored high in relative fuel utilization. Other storage systems (i.e., paraffin storage and thermal wells) could equal the energy savings associated with water storage, none was found to exceed it. As indicated earlier, the application of "electrical" storage devices do not result in the reduction of IUS fuel consumption.

Water storage systems having the additional advantage of utilizing present day technology. While (1) further development work is required in several areas (e.g., efficient baffling techniques and methods of minimizing pumping requirements), and (2) water storage systems are not considered off-the-shelf items, successful water storage systems similar to those which would be required for IUS have been constructed.

Disadvantages of water storage systems can be attributed to their large size, their somewhat limited expansion capability, and the extensive on-site construction effort which is required.

TABLE 44. SUMMARY OF SCORING FOR SELECTION OF PRIMARY E/S CANDIDATE FOR 1000-UNIT APARTMENT IUS

Criteria	Weight	Energy Storage Alternative, raw score						
		No Storage	Electrochemical	Chemical	Compressed Air	Inertial	SMES	Thermal
Net Relative Cost	2	5	4	2	5	2	1	7
Relative Fuel Utilization	1.4	5	5	5	5	5	5	7
Safety	1.2	5	3	3	5	3	3	5
Availability/Reliability/ Maintainability	1.1	5	3	5	5	3	7	5
Hardware Availability	1.1	5	3	3	3	3	1	4
Environmental Concerns	0.8	5	5	5	3	5	3	5
Energy Storage Density	0.6	5	3	3	1	3	4	2
Expansion Capability	0.6	5	7	5	3	5	3	3
Transportability	0.2	5	5	5	3	3	3	3
Total Raw Score		45	38	36	33	32	30	41
Total Weighted Score		45	36.2	33.2	37.2	30.6	28.6	47.3

TABLE 45. SUMMARY OF SCORING FOR SELECTION OF PRIMARY E/S CANDIDATE FOR VILLAGE COMPLEX IUS

Criteria	Weight	Energy Storage Alternative, raw score						
		No Storage	Electrochemical	Chemical	Compressed Air	Inertial	SMES	Thermal
Net Relative Cost	2	5	5	2	5	4	2	7
Relative Fuel Utilization	1.4	5	5	5	5	5	5	6
Safety	1.2	5	3	3	5	3	3	5
Availability/Reliability/ Maintainability	1.1	5	3	5	5	3	7	5
Hardware Availability	1.1	5	3	3	3	3	1	4
Environmental Concerns	0.8	5	5	5	3	5	3	5
Energy Storage Density	0.6	5	3	3	1	3	4	2
Expansion Capability	0.6	5	7	5	3	5	3	3
Transportability	0.2	5	5	5	3	3	3	3
Total Raw Score		45	39	36	33	34	31	40
Total Weighted Score		45	38.2	33.2	37.2	34.6	30.6	45.9

INTEGRATION CONSIDERATIONS FOR WATER STORAGE SYSTEMS

Water storage has been selected as the primary candidate for energy storage in conjunction with Integrated Utility Systems. The original work statement and study plan defining these investigations called for a detailed consideration of the integration aspects of the primary candidate. During the course of the investigations, however, it was determined that the assessment of energy storage in climates other than Washington, D.C., would be of greater value and the time and resources were allotted accordingly. It is appropriate, however, to discuss several of the integration considerations which were identified and addressed throughout the study.

One of the advantages of water storage systems for IUS application is that these systems have the ability to function in the heat storage mode during the winter months as well as in the cold storage systems during the summer. Since each of these storage modes obviously will require different integration techniques, it is desirable to address each of the methods separately.

Chilled Water Storage

Integration of a chilled water storage system with IUS is dependent on the characteristics of the chillers and the chilled water distribution system. For the purposes of this study, it has been assumed that chilled water is distributed to the various buildings being served at a temperature of 280 K (45 F) and is returned at 287 K (57 F). Control of the system is assumed to be by variable flow rate. That is, for part load operation, the chilled water flow rate is reduced and a nearly constant return water temperature is maintained. The 280 K (45 F) send-out temperature is maintained by varying the number of chillers which are on line. The chillers are assumed to be in parallel such that each machine operates between the same supply and return temperatures.

A number of schemes for integrating the chilled water storage tank with the IUS have been identified and two leading possibilities are presented in Figures 11 and 12. These two systems are identical during charging when excess 280 K

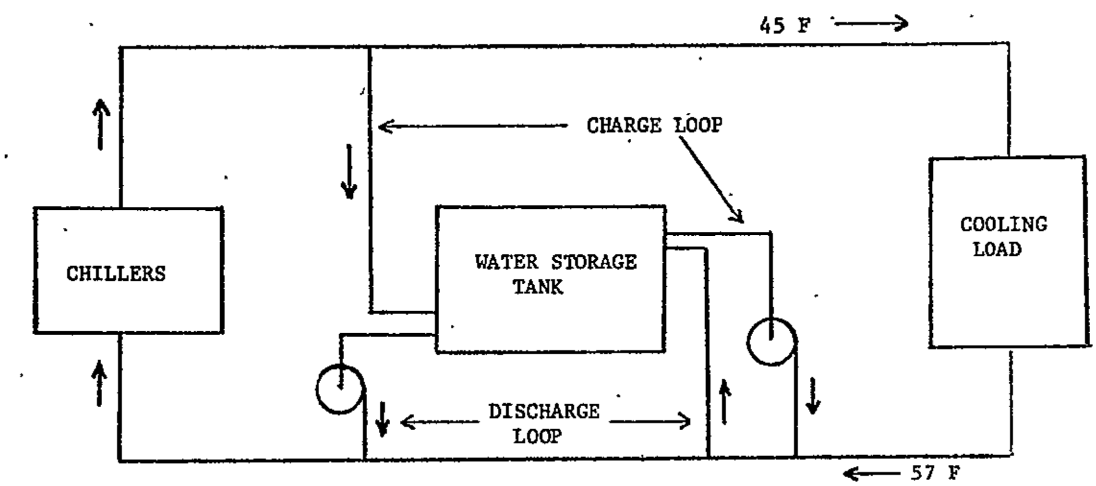

FIGURE 11. CHILLED WATER STORAGE TYPE A INTEGRATION

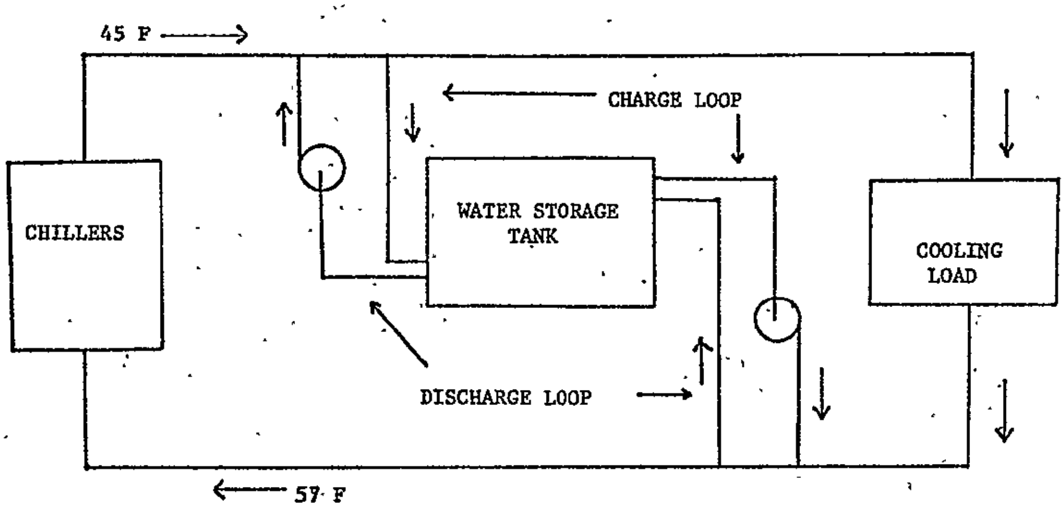

FIGURE 12. CHILLED WATER STORAGE TYPE B INTEGRATION

(45 F) chilled water is routed into storage while warmer water in storage is withdrawn and blended with return water. The two systems differ, however, in the way that the storage is discharged. For the concept shown in Figure 11 (which is referred to as a chilled water Type A integration), return water is diverted into storage and chilled water from storage is mixed with the remaining return flow, the net result is that the temperature of the return water which is supplied to the chillers is reduced. Since the send-out temperature remains constant, the chillers will now be able to handle a greater flow rate. This procedure has the advantage of being able to use nearly all of the stored energy without regard to the temperature of the water drawn from storage (provided, of course, that sufficient flow rates can be maintained). The system is undesirable, however, due to the fact that the lower chiller inlet temperature will decrease the COP of those machines.

The integration concept shown in Figure 12 (referred to as a chilled water Type B integration) is discharged by diverting return water to storage while supplying chilled water directly to the supply main of the distribution system. Thus, a portion of the return water bypasses the chiller completely. The chillers may therefore operate with their design temperature drop and design flow rate resulting in optimum performance. The disadvantages of this concept is the fact that, as the tank is discharged, its average temperature will rise. If this rise in tank temperature is reflected in an increased storage discharge water temperature, the water drawn from storage will eventually become unusable.

The disadvantages of the second system could be overcome by providing a method of preventing direct mixing of the inlet and outlet flows. From a thermal standpoint, a two tank arrangement would be desirable in which the tanks are alternately filled and emptied. A two tank approach would, however, be prohibitive from a cost standpoint. Alternately, a series of tanks or a baffling system could be used to approach the performance of a two tank arrangement. The exact method of obtaining the necessary stratification has not been determined in this study and further investigations in this area are recommended. It appears, however, that adequate techniques can be developed and the integration concept presented in Figure 12 is, therefore, suggested for application to IUS.

Hot Water Storage

The hot water distribution system operates with a send-out temperature of 367 K (200 F) and a return temperature of 333 K (140 F). As for the chilled water system, a variable flow rate arrangement is assumed for control of the return temperature. The integration of heat storage systems with the IUS is complicated by the fact that heat recovery takes place at several temperature ranges. Lube oil recovered energy is assumed, for this study, to take place at a temperature of 355 K (180 F) while high grade energy is in the form of 394 K (250 F) steam. Since the send-out temperature of the distribution system is 367 K (200 F) it is obvious that some high grade energy will always be required. In order to account for lube oil heat exchanger effectiveness of less than 1, a maximum lube oil heat exchanger output temperature of 350 K (170 F) has been assumed.*

A possible integration arrangement for hot water storage systems is shown in Figure 13. The arrangement (which is referred to as a hot water Type A integration) is similar to the suggested (Type B) cold storage scheme in that the storage is essentially in parallel with the heat sources. Thus the temperature of the water entering the lube oil heat exchanger is maintained at a low temperature during discharge promoting efficient heat transfer.

Difficulties with this system can arise, however, due to the variability of the sources and demands for thermal energy. For example, it has been observed that, under certain conditions, there is ample low grade energy available to preheat the return flow to the maximum low grade heat exchanger exit temperature of 350 K (170 F), but that the quantity of high grade energy available is not sufficient to bring the flow to its final temperature of 367 K (200 F). In order to make up the deficit in high grade energy, storage must be utilized. In the hot water Type A integration depicted in Figure 13, a portion of the return water would be diverted to storage thus reducing the flow of water through both the heat exchangers. This results in an increase in the amount of low grade energy which must be discarded--an obviously undesirable consequence.

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* This assumption is consistant with previous IUS studies (1 and 2).

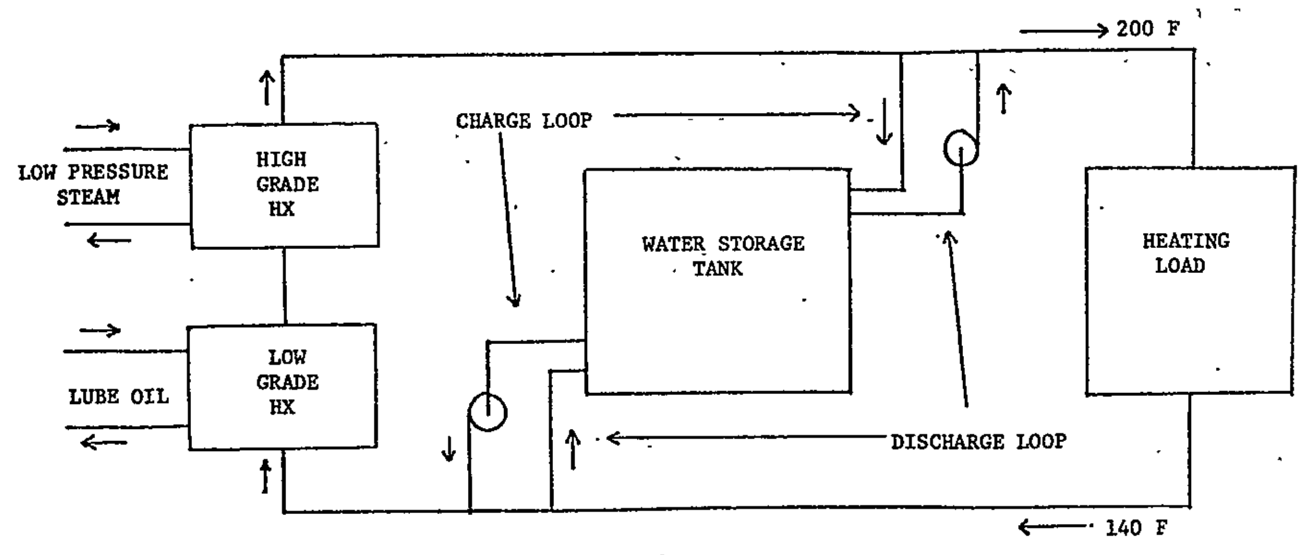

FIGURE 13. HOT WATER STORAGE TYPE A INTEGRATION

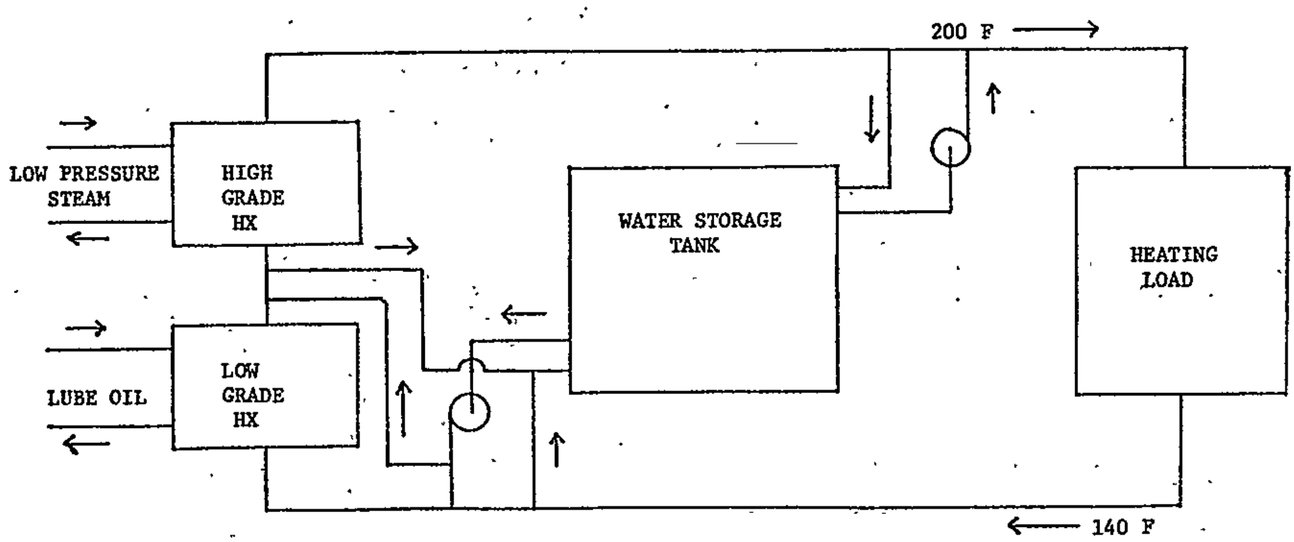

FIGURE 14. HOT WATER STORAGE TYPE B INTEGRATION

The difficulties described in the preceding paragraph can be overcome by providing a means of utilizing some of the excess low grade energy to preheat the water which is diverted to storage during discharge. A method of accomplishing this is shown schematically in Figure 14. This arrangement (which is referred to as a hot water Type B integration) has the capability of being charged or discharged either upstream or downstream of the lube oil heat exchanger. Therefore, during those periods when ample low grade energy is available but extra high grade energy is needed, the storage tank will be discharged by diverting water to the tank after it has been preheated in the lube oil exchanger. The added flexibility of the hot water Type B system makes this arrangement the preferred method of integration for hot water storage in connection with IUS.

Combined Heat and Cold Storage

The water storage tanks will be required, for economic reasons, to operate at atmospheric pressure. Pumps will therefore be installed to withdraw water from storage and raise its pressure to line pressure. For ease of presentation, the previous schematics depicting integration concepts have shown separate pumps for both charging and discharging. By appropriate piping and valving, however, the same pump may be used for both functions. Figure 15 is a schematic diagram of a water storage system integrated with an IUS showing the piping and valving required for both winter and summer operation. The storage pump has been shown as discharging at points of low pressure in the distribution system in order to minimize both the energy requirements for pumping and the pump capacity required.

An important consideration for combined hot and cold storage systems will be the procedure for switching from one mode of storage to the other. Fortunately, the changeover process can be a gradual one occurring during the autumn and spring when excess heat is available. Absorption chillers can utilize this excess heat to bring the storage tank to its charged state prior to the start of the cooling season while excess recovered heat may be used to charge the heat storage system prior to the heating season.

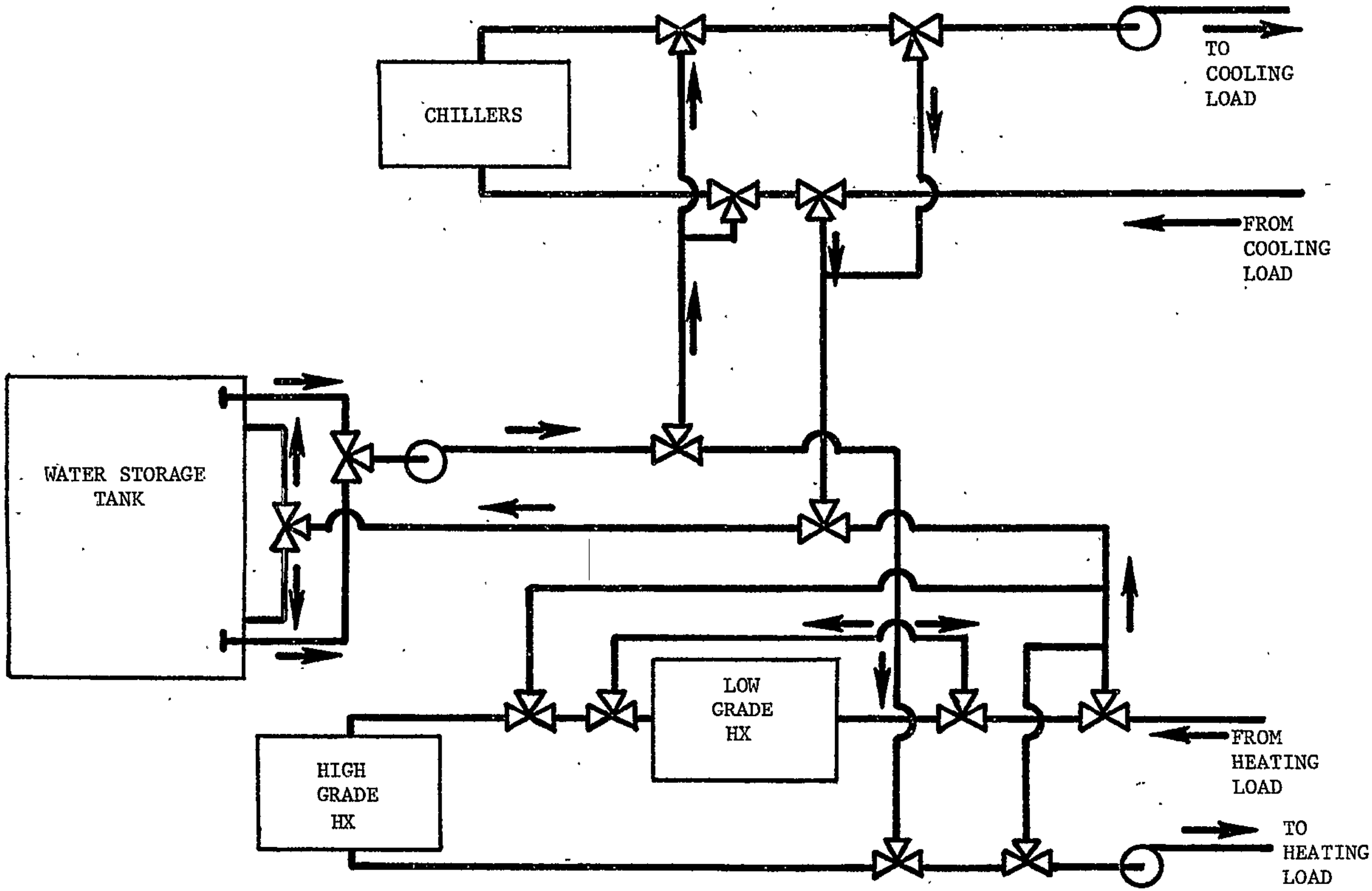

FIGURE 15. COMBINED HOT AND CHILLED WATER STORAGE SYSTEM INTEGRATED WITH IUS

ASSESSMENT OF WATER STORAGE SYSTEMS IN ALTERNATE CLIMATES

Water storage was selected as the primary energy storage candidate as a result of analysis of IUS baselines with climates similar to Washington, D.C. The effect of alternate climates on the performance of water storage systems was assessed through the use of load profiles for a similar (but not identical) 1000-Unit Apartment in Houston, Texas, and Minneapolis, Minnesota. Since the profiles for identical community models were not available, direct site-to-site comparisons to the Washington, D.C. case are not possible. The resulting trends are, however, considered meaningful.

The results of the computer runs are summarized in Table 46. The data for annual fuel consumption are of particular interest and the results indicate that a water storage system will reduce energy consumption for a 1000-Unit Apartment located in Minneapolis by about 3 percent but will slightly increase the energy consumption of a Houston installation. This result is as expected since the Houston IUS no-storage baseline does not require auxiliary heating on winter average days and only a small amount is required on winter design days. It is apparent that storage for the Houston IUS will only be useful as a result of the replacement of generating capacity which would otherwise be necessary to satisfy peak cooling demands during the summer months.

The economics of water storage systems were examined for both Minneapolis and Houston IUS installations and the results are summarized in Tables 47 and 48, respectively. The analysis shows that water storage systems will be economically profitable in both locations but the profitability will be greater for the Minneapolis installation due to the added benefit of substantial fuel savings coupled with a slightly smaller storage requirement.

It should be pointed out that, in order to be consistant with other storage cases, the economic data for the Minneapolis case include a credit for replacement of auxiliary boilers. It may, however, be desirable to retain some boilers since the storage system (which has been sized based on the summer

TABLE 46. SUMMARY OF PERFORMANCE AND CAPACITIES FOR 1000-UNIT APARTMENT IUS IN ALTERNATE CLIMATES[(a)]

Item	Minneapolis	Houston
Annual fuel consumption, m^3 (thousands of gallons)		
No-storage	3217 (850)	3399 (898)
Water-storage	3111 (822)	3410 (901)
Cold storage required, GJ (ton-hours)	36.5 (2880)	44.7 (3531)
Heat storage required, GJ (millions of Btu)	113 (107)	13 (12)
Compression chiller capacity, Tons		
No-storage	662	751
Water-storage	700	850

(a) Four, 478-kw generator sets assumed for storage cases.

TABLE 47. NET RELATIVE COST OF A WATER STORAGE SYSTEM INSTALLED IN A MINNEAPOLIS 1000-UNIT APARTMENT IUS

Item	Cost, Thousands of Dollars	Cost Discounted to Installation Date, Thousands of Dollars			
		Case[a] A	Case[a] B	Case[a] C	Case[a] D
Installed Cost of Storage System	104				
Credit for Generators Replaced[b]	-216				
Credit for Boilers Replaced	-48				
Credit for Chillers Replaced					
Net First Cost of Storage	-160	-160	-160	-160	-160
Net Annual Fuel Costs	-10.2	-104	-64	-153	-85
Net O&M Costs					
Life Cycle Cost of Storage System		-264	-224	-313	-245
Life Cycle Cost of "No Storage" Options		8960	6710	10,850	7560
Net Relative Cost		0.971	0.967	0.971	0.966
Score		8	8	8	8

(a) Case A - 7-1/2 percent per year discount rate, no fuel escalation.
Case B - 15 percent per year discount rate, no fuel escalation.
Case C - 7-1/2 percent per year discount rate, 5 percent per year fuel escalation.
Case D - 15 percent per year discount rate, 5 percent per year fuel escalation.

(b) Two generator sets replaced.

TABLE 48. NET RELATIVE COST OF A WATER STORAGE SYSTEM INSTALLED IN A HOUSTON 1000-UNIT APARTMENT IUS

Item	Cost, Thousands of Dollars	Cost Discounted to Installation Date, Thousands of Dollars			
		Case[a] A	Case[a] B	Case[a] C	Case[a] D
Installed Cost of Storage System	128				
Credit for Generators Replaced[b]	-216				
Credit for Boilers Replaced	- 48				
Net First Cost of Storage	-136	-136	-136	-136	-136
Net Annual Fuel Costs	~ 0				
Net O&M Costs	~ 0				
Life Cycle Cost of Storage System		-136	-136	-136	-136
Life Cycle Cost of "No Storage" Options		8960	6710	10,850	7560
Net Relative Cost		0.984	0.980	0.987	0.982
Score		7	7	6	7

(a) Case A - 7-1/2 percent per year discount rate, no fuel escalation.
Case B - 15 percent per year discount rate, no fuel escalation.
Case C - 7-1/2 percent per year discount rate, 5 percent per year fuel escalation.
Case D - 15 percent per year discount rate, 5 percent per year fuel escalation.

(b) Two generators replaced.

design day requirements) will satisfy the heating load for only about 2 consequtive winter design days. Retaining all of the auxiliary boilers would increase the net relative cost of the Minneapolis system slightly.

Table 49 presents a summary of the assessment criteria scores for the water storage systems in Minneapolis and Houston. The results demonstrate that a Minneapolis installation will be preferred over a Houston water storage installation. For the Houston case, it appears that the advantages of reduced net relative cost are offset by reduced hardware availability, energy storage density, expansion capability, and transportability and that water storage systems should not be recommended for a Houston location.

TABLE 49. SUMMARY OF SCORING FOR WATER-STORAGE SYSTEMS IN ALTERNATE CLIMATES

Criteria	Weight	No-Storage	Minneapolis	Houston
Net Relative Cost	2.0	5	8	7
Relative Fine Utilization	1.4	5	8	5
Safety	1.2	5	5	5
Availability/Reliability/ Maintainability	1.1	5	5	5
Hardware Availability	1.1	5	4	4
Environmental Concerns	0.8	5	5	5
Energy Storage Density	0.6	5	2	2
Expansion Capability	0.6	5	3	3
Transportability	0.2	5	3	3
Total Raw Score		45	43	39
Total Weighted Score		45	50.7	44.5

REFERENCES

(1) NASA-Urban Systems Project Office Report, "Preliminary Design Study of a Baseline MIUS System", (April, 1974).

(2) NASA-Urban Systems Project Office Report, "MIUS Community Conceptual Design Study", (April, 1974).

(3) Churchman, C. W., and Ackoff, R. L., "An Approximate Measure of Value", Journal of the Operations Research Society of America, Vol. 2, No. 2, (May, 1954).

APPENDIX A

PROCEDURE FOR COMPARATIVE ECONOMIC ASSESSMENT OF ALTERNATIVE STORAGE METHODS

APPENDIX A

PROCEDURE FOR COMPARATIVE ECONOMIC ASSESSMENT OF ALTERNATIVE STORAGE METHODS

The economic profitability of energy storage devices imbedded in IUS is determined by calculation of the net relative cost of the storage device. Net relative cost is defined as the ratio of the life cycle cost of the IUS with energy storage to the life cycle cost of the no-storage IUS option. This may be expressed in equation form as

$$NRC = (LCIUS + \Delta ES)/LCIUS$$

where

NRC = Net Relative Cost

LCIUS = Life cycle cost of no-storage IUS

ΔES = Incremental life cycle cost due to the addition of energy storage to the no-storage IUS.

This equation reduces to

$$NRC = 1 + \Delta ES/LCIUS$$

where the symbols are defined as before.

Although the absolute economic profitability of energy storage systems can be determined from the calculation of ΔES alone, it was felt that this number would not be meaningful unless compared to the costs of the entire IUS. Net relative cost was therefore defined in an attempt to normalize the economic profitability of energy storage devices.

Assumptions

The assumptions which were utilized in carrying out the economic comparisons are summarized below.

(1) The analysis was carried out in constant 1975 dollars

(2) All costs were adjusted to effective prices for July, 1975

(3) Labor rates for Washington, D.C. area were used where applicable

(4) Discount rates of 7.5 and 15 percent were used for the present value analysis

(5) A twenty year life was assumed for IUS

(6) Fuel price (No. 2 Diesel) was assumed to be 36¢/ gallon

(7) Fuel price escalation of 0 and 5 percent per year

(8) Taxation effects were not considered.

A number of these assumptions will be discussed in further detail in the following sections.

Inflation

The results of a present value analysis are not affected by inflation so long as all costs are subject to the same inflation rate. Since it was not reasonable to predict different inflation rates for the different IUS cost elements over the assumed 20 year IUS lifetime, an inflation rate of zero was assumed for all costs addressed with the exception of the fuel costs. Fuel price is addressed in greater detail in the next section.

Fuel Price

Both IUS baselines considered in this study utilized No. 2 diesel fuel. The cost of the fuel is, of course, an important parameter in carrying out the economic assessment of alternative energy storage systems. Projections of fuel price increases over the assumed 20 year IUS life are highly speculative as petroleum prices will continue to be strongly influenced by political considerations, and unforeseen political decisions could significantly alter any assumed scenario. Preliminary studies indicate, however, that the wholesale price of fuel oil in constant 1975 dollars can be expected to increase from a present cost of about 29¢/gal to 36¢/gal. by 1979. In an attempt to bracket the effect

of possible fuel price increases after this date, fuel price escalation rates of 0 and 5 percent per year were assumed. It should be pointed out that (since the analysis is carried out in constant 1975 dollars) these escalation rates correspond to current price increases of to 0 and 5 percent above the general inflation rate.

Taxation

The tax status of IUS installations has not been clearly defined. Early installations will be of a demonstration nature and will probably be funded through government agencies. It is hoped, however, that IUS will eventually become a private operation subject to taxation by local, state, and federal governments. The difficult question of tax status was not treated in this study and the economic comparisons are considered to be before taxes.

Present Worth Factors

The present value analysis procedure utilized in this study converts all of the costs of a system over the assumed 20 year life to an equivalent cost at the time of installation through the use of present worth factors. This can be expressed via the equation

$$\left\{\begin{array}{l}\text{Net Present}\\ \text{Value of}\\ \text{Method A}\end{array}\right\} = \sum_{n=o}^{L} \left(\frac{An}{(1+i)^{n}}\right)$$

where

An = net cost for period, n
i = discount rate
L = life of project
n = period.

If costs or benefits are uniform over the life of the project, uniform series present value factors may be used.

$$\left\{\begin{array}{l}\text{Net Present} \\ \text{Value of} \\ \text{Uniform} \\ \text{Series}\end{array}\right\} = A \frac{(1+i)^L - 1}{i\,(1+i)^L}$$

where i and L are as before and

A = annual net cost assumed to be uniform over the life of the project.

If costs or benefits are assumed to increase at a uniform rate over the life of the project (e.g., fuel costs), the following equation may be used.

$$\left\{\begin{array}{l}\text{Net Present} \\ \text{Value of} \\ \text{Uniform} \\ \text{Gradient} \\ \text{Series}\end{array}\right\} = Ao \frac{1}{1+i} \left(\frac{1-X^L}{1-X}\right)$$

where i and L are as before and

$X = \frac{1+r}{1+i}$

r = escalation rate

Ao = net cost subject to escalation for first year of project.

The series present value factors utilized in this study are summarized in Table A-1.

Baseline IUS Costs

The life cycle costs of the IUS baselines utilized in the study (LCIUS) are required in order to calculate the net relative cost of the energy storage systems under consideration. These costs were taken from References 1 and 2 and were adjusted (using the Wholesale Price Index) to 1975 levels. In addition, fuel costs were adjusted to reflect the assumed 36¢/gallon fuel price. Table A-2 summarizes the data utilized. It should be pointed out that the costs for the Village Complex were assumed to be one eighth of the costs for the "Option II" costs reported in Reference 2. Option II consists of 7 Village Complex IUS installations and a Central Business District IUS. The error introduced by the approximation is thought to be well within the accuracy of the cost estimates.

TABLE A-1. SERIES PRESENT WORTH FACTORS USED IN COMPARATIVE ECONOMIC ASSESSMENT

Discount Rate, percent	Escalation Rate, percent	Present Worth Factor[a]
7.5	0	10.194
15.0	0	6.259
7.5	5	15.015
15.0	5	8.379

(a) 20 year life assumed.

TABLE A-2. COST INFORMATION FOR IUS BASELINES

Item	1000-Unit Apartment	Village Complex
Capital Cost, $	2,708,000[a]	29,870,000[b]
Fuel and Lube Cost, $/yr	214,000[a]	627,000[b]
Other O&M Costs, $/yr	221,000[a]	979,000[b]
Capital Cost, 1975 $	3,141,000	39,692,000
Fuel and Lube, 1975 $/yr	315,000	921,000
Other O&M Costs, 1975 $/yr	256,000	1,301,000
Life Cycle Cost,[c] Millions of $	8.96	62.3
Life Cycle Cost,[d] Millions of $	6.71	53.6
Life Cycle Cost,[e] Millions of $	10.5	66.8
Life Cycle Cost,[f] Millions of $	7.38	55.8

(a) Reported in Reference 1.
(b) Reported in Reference 2 and adjusted.
(c) Fuel escalation rate of 0%, Discount rate or 7.5%.
(d) Fuel escalation rate of 0%, Discount rate of 15%.
(e) Fuel escalation rate of 5%, Discount rate of 7.5%.
(f) Fuel escalation rate of 5%, Discount rate of 15%.

Energy Storage System Costs

The absolute economic profitability (ΔES) of the alternative energy storage devices is calculated on an incremental basis. That is, the costs associated with an energy storage device are treated as net costs and are computed by taking credit for fuel savings and equipment reduction relative to the baseline no-storage system. The factors which are included in the calculation are all discounted to the installation date and are defined below:

(1) First Cost - those costs which are associated with installation and startup of the energy storage system including capital equipment land, construction and one time startup costs.

(2) Fuel Costs - Net cost of the fuel consumed by the IUS system with energy storage relative to the no-storage baseline.

(3) Other O&M Costs - Net cost of operation and maintenance of the energy storage system excluding fuel costs.

(4) Replacement Costs - Net cost of replacing unusable equipment at a specified future date.

(5) Salvage Value - Net credit received due to the disposal of equipment at the end of the assumed economic lifetime.

Since the calculation of ΔES involves taking appropriate credits for equipment replaced, the costs of this equipment must be estimated. The following cost estimates were used for this study.

Diesel generator sets
- 1000-Unit Apartment (478 kw) - $108,000 each
- Village Complex (4415 kw) - $768,200 each

Auxiliary boilers
- 1000-Unit Apartment (250 hp) - $24,200 each
- Village Complex (500 hp) - $37,000 each.

Example Calculation

To illustrate the procedure utilized in calculating the net relative cost of an energy storage device, a numerical example is presented below. The case examined is for a water storage system for application to the 1000-Unit Apartment IUS. Appropriate cost data for this case are as follows:

Installed cost of storage system - \$154,000
Credit for generator sets replaced - \$216,000
Credit for auxiliary boilers replaced - \$48,400
Annual fuel savings - \$7,200
Net salvage value - ~0
Net other O&M costs - ~0.

The net first costs (NFC) are calculated as

$$NFC = \$154,000 - \$216,000 - \$48,400 = -\$110,400 \quad .$$

The negative sign indicates that there is a net savings in first costs due to the installation of water storage.

The fuel costs (FC) must be discounted to the installation date using appropriate series present worth factors.

FC (7.5% discount, 0% escalation) = -7,200 (10.194) = -\$73,400
FC (15%, 0%) = -7,200 (6.259) = -\$45,060
FC (7.5%, 5%) = -7,200 (15.015) = -\$108,100
FC (15%, 5%) = -7,200 (8.379) = -\$60,330.

Again, the negative sign indicates a net savings due to the energy storage device. Since there are no replacement costs associated with the water storage system (20 year life expected) and the net O&M and salvage values have been assumed to be zero, ΔES may be calculated as

$$\Delta ES = NFC + FC$$

or

$$\Delta ES\ (7.5\%\ \text{discount},\ 0\%\ \text{escalation}) = -110{,}400 - 73{,}400 = -183{,}800$$

$$\Delta ES\ (15\%,\ 0\%) = -110{,}400 - 45{,}060 = -155{,}460$$

$$\Delta ES\ (7.5\%,\ 5\%) = -110{,}400 - 108{,}100 = -218{,}500$$

$$\Delta ES\ (15\%,\ 5\%) = -110{,}400 - 60{,}330 = -170{,}730.$$

The net relative cost is then calculated as

$$NRC = 1 + \Delta ES/LCIUS$$

or

$$NRC\ (7.5\%\ \text{discount},\ 0\%\ \text{escalation}) = 1 - 183.8/8{,}960 = 0.979$$

$$NRC\ (15\%,\ 0\%) = 1 - 155.5/6{,}710 = 0.977$$

$$NRC\ (7.5\%,\ 5\%) = 1 - 218.5/10{,}500 = 0.979$$

$$NRC\ (15\%,\ 5\%) = 1 - 170.7/7{,}380 = 0.977.$$

It should be noted that, although the absolute profitability (ΔES) for the system varies considerably for the different discount and escalation rates, the net relative costs vary only slightly. This is because the assumed discount and escalation rates also affect the life cycle cost of the baseline system (LCIUS) in a similar manner and variations tend to cancel. Thus, net relative cost appears to be somewhat insensitive to discount rate and fuel escalation assumptions.

APPENDIX B

DESCRIPTION AND LISTING OF THE IUS SIMULATION COMPUTER PROGRAM

APPENDIX B

DESCRIPTION AND LISTING OF THE IUS SIMULATION COMPUTER PROGRAM

The purpose of the IUS simulation computer program IUSMOD is to enable the comparison of alternative energy storage devices on the common basis of annual energy consumption of IUS/energy storage configurations. In addition, the program allows the determination of the capacities of IUS equipment (including energy storage equipment) required to satisfy input load profiles. The program IUSMOD, which is written in FORTRAN, is basically a modification of the ESOP computer program utilized by NASA-JSC. It calculates the fuel required by prime movers and auxiliary boilers to supply the electrical, space heating, space cooling, and water heating requirements of the baseline communities. The program in its current form, IUSMOD, treats heat storage, cold storage, and electrical storage.

Input required by the program includes the hour-by-hour demand profiles for hot water heating, space heating, space cooling, and electricity. The performance parameters for the various IUS components (boilers, chillers, etc.) are also input, as well as appropriate flags which describe the case being run. Program output consists of the calculated fuel utilization, generator output, chiller output, waste heat recovered, and energy flow to and from storage for each hour of the period under consideration.

The program is a relatively simple analytical tool intended for preliminary sizing of storage schemes and rough estimates of annual fuel consumption of alternative IUS designs. Results of the program appear to agree reasonably well with output from the ESOP program when similar input data are used.

Program Description

The Integrated Utility System Simulation program, IUSMOD, developed in this study contains a main program, BIUSS, which reads input data, prints results, and controls the logic flow. BIUSS is modular in nature with different sections

of the main program devoted to performing the calculations required for different energy storage arrangements. Currently the BIUSS program will treat any one of four configurations depending on the value of the input flag MODESTO. Included are the no-storage configuration (MODESTO = 1), thermal storage (MODESTO = 2), electrical storage to match thermal demands (MODESTO = 3), and electrical storage for peak shaving (MODESTO = 4).

The main program calls the subroutine HEAT, which calculates the excess heat available or the auxiliary heat required after satisfying space heating and domestic hot water heating loads. HEAT, in turn, calls the subroutine GENRAT which calculates the fuel consumption and the quantities of high and low grade heat production of the prime movers given the electrical demand. GENRAT utilizes data which is contained in the block data routine GENDATA. Subroutine ELECSTO calculates the energy flow to and from electrical storage systems taking into account charging, standby, and discharging inefficiencies.

```
      PROGRAM BIUSS(INPUT,OUTPUT,TAPE1,TAPE60=INPUT)
C
C                          * * * * * * * * * * * * * *
C                          *  B A T T E L L E        *
C                          *  I N T E G R A T E D    *
C                          *  U T I L I T Y          *
C                          *  S Y S T E M            *
C                          *  S I M U L A T I O N    *
C                          * * * * * * * * * * * * * *
C
C     = PROGRAM BIUSS SIMULATES THE GENERATION OF POWER AND THE
C       PRODUCTION OF HEATING, COOLING, AND HOT WATER TO SATISFY
C       THE UTILITY NEEDS OF LARGE RESIDENTIAL UNITS OR SMALL TOWNS.
C
C     = MAIN INPUT DATA REQUIRED%
C         ITITL1  = 80 CHAR. TITLE OF SIMULATION RUN
C         MODESTO = TYPE OF STORAGE TO BE USED
C         IGEN    = TYPE OF GENERATOR TO BE USED
C         NUMGEN  = MAXIMUM NO. OF GENERATORS TO BE USED
C         FV      = FUEL HEATING VALUE                      (BTU/GAL)
C         BEFF    = BOILER EFFICIENCY
C         COPA    = COEFF OF PERFORMANCE OF ABSORPTION A/C
C         COPC    = COEFF OF PERFORMANCE OF COMPRESSION A/C
C         TLO     = TEMP OF RECOVERED LOW-GRADE HEAT           (F)
C         THOT    = TEMP OF DOMESTIC HOT WATER SUPPLY          (F)
C         TWS     = TEMP OF SUPPLY WATER                       (F)
C         IDAY    = DAY NUMBER  (0 OR 1 MEAN NO PREVIOUS DAYS)
C         ISESON  = SEASON FLAG  (1-WIN, 2-SPR, 3-SUM, 4-AUT)
C         I       = DATA FLAG  (ZERO OR BLANK, READ NEW DATA -
C                                      1, USE OLD DATA)
C         ITITL2  = 60 CHAR. DESCRIPTION OF SIMULATION DAY
C         OHWD    = HOURLY DOMESTIC HOT WATER DEMAND        (BTU/HR)
C         SHETD   = HOURLY SPACE HEATING DEMAND             (BTU/HR)
C         TOND    = HOURLY AIR CONDITIONING DEMAND           (TONS)
C         DEKW    = HOURLY DOMESTIC ELECTRICAL DEMAND          (KW)
C         AUXKW   = HOURLY AUXILIARY ELECTRICAL DEMAND         (KW)
C         OQRCV   = HOURLY OTHER HEAT RECOV  (INCINERATION) (BTU/HR)
C
C     = EXTRA INPUT DATA FOR THERMAL STORAGE  (MODESTO=2)
C         STOMAXH = MAX. STORAGE CAPACITY - HOT WATER          (BTU)
C         STOMAXC = MAX. STORAGE CAPACITY - COLD WATER      (TON-HR)
C         QINMAXH = MAX. STORAGE INPUT RATE - HOT WATER     (BTU/HR)
C         QOTMAXH = MAX. STORAGE OUTPUT RATE - HOT WATER    (BTU/HR)
C         TNINMAX = MAX. STORAGE INPUT RATE - COLD WATER      (TONS)
C         TNOTMAX = MAX. STORAGE OUTPUT RATE - COLD WATER     (TONS)
C         TONCMAX = MAX. CAPACITY OF COMPRESSION A/C          (TONS)
C         PCTFIL  = PERCENT CAPACITY FILLED AT SIMULATION START
C         PCTLSTH = PERCENT CAPACITY LOST DURING HOUR - HOT
C         PCTLSTC = PERCENT CAPACITY LOST DURING HOUR - COLD
C
C     = EXTRA INPUT DATA FOR ELECTRICAL STORAGE  (MODESTO=3)
C         SEDMAXC = MAX. STORAGE CHARGE RATE                   (KW)
C         SEDMAXD = MAX. STORAGE DISCHARGE RATE                (KW)
```

Program Listing

```
      C              STKWMAX = MAX. STORAGE CAPACITY                         (KW)
      C              STPCIN  = PERCENT CAPACITY CHARGED AT START
      C              EFFCHG  = EFFICIENCY OF CHARGING
      C              EFFSBY  = EFFICIENCY OF STAND-BY
      C              EFFDIS  = EFFICIENCY OF DISCHARGE
      C
      C          =  EXTRA INPUT DATA FOR CONST. LOAD ELECT. STOR.  (MODESTO=4)
      C              ***  USE SAME AS FOR MODESTO=3 PLUS%
      C              GENAVG  = AVERAGE OUTPUT OF GENERATORS                   (KW)
      C
      C          =  OTHER IMPORTANT VARIABLES IN PROGRAM%
      C              BFUEL   = BOILER FUEL USAGE                          (GAL/HR)
      C              CED     = COMPRESSION A/C ELECTRICAL DEMAND              (KW)
      C              DED     = DOMESTIC + AUXIL ELECTRICAL DEMAND             (KW)
      C              GENKW   = PRIME MOVER ELECTRICAL OUTPUT                  (KW)
      C              HRE     = HEAT RATE OF PRIME MOVER                  (BTU/KWH)
      C              OILCQ   = LOW-GRADE HEAT RECOVERED                   (BTU/HR)
      C              PMFUEL  = PRIME MOVER FUEL USAGE                     (GAL/HR)
      C              PMORCV  = HIGH-GRADE HEAT RECOV FROM GENERATOR       (BTU/HR)
      C              QAABS   = HEAT AVAILABLE FOR ABS A/C                 (BTU/HR)
      C              QABS    = HIGH-GRADE HEAT USED FOR ABS A/C           (BTU/HR)
      C              QBOIL   = HEAT FROM BOILER                           (BTU/HR)
      C              QHWAO   = HOT WATER DEMAND NOT MET BY L-G HEAT       (BTU/HR)
      C              QOILA   = LOW-GRADE RECOV HEAT NOT UTILIZED          (BTU/HR)
      C              QOILW   = LOW-GRADE RECOV HEAT USED FOR DOMESTIC
      C                          HOT WATER AND SPACE HEATING              (BTU/HR)
      C              QWSTD   = HEAT WASTED                                (BTU/HR)
      C              SED     = STORAGE ELECTRICAL DEMAND                      (KW)
      C              STKW    = ENERGY IN ELECTRICAL STORAGE                   (KW)
      C              STO     = ENERGY IN THERMAL STORAGE         SUMMER-    (TONS)
      C                                                     OTHER SEAS-  (BTU/HR)
      C              TONA    = ABSORPTION AIR CONDITIONING                  (TONS)
      C              TONC    = COMPRESSION AIR CONDITIONING                 (TONS)
      C              TORCV   = TOTAL HIGH-GRADE HEAT RECOVERED            (BTU/HR)
      C
      C          =  WRITTEN BY C. P. CRALL AND M. R. NEALE                  (1975)
      C
      C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      C
            COMMON /IN/ STO(25),QBOIL(24),QAABS(24),QQRCV(24),QHWD(24),
           $   QOILW(24),QOILA(24),PMORCV(24),QHWAO(24),TQRCV(24),QABS(24),
           $   QWSTD(24),OILCQ(24),PMFUEL(24),BFUEL(24),CED(24),DED(24),
           $   TONA(24),TONC(24),TOND(24),SHETO(24),HRE(24),AUXKW(24),DEKW(24)
           $  ,GENKW(24),SED(24),TLO,THOT,TWS
            COMMON /MISC/ FV,BEFF,COPA,COPC,DBFUEL,DPMFUEL,DTONA,DTONC,DCED,
           $   DGENKW,DTQRCV,DQWSTD,STOMAXH,STOMAXC,QINMAXH,QOTMAXH,TNINMAX,
           $   TNOTMAX,TONCMAX,PCTIFIL,PCTLSTH,PCTLSTC
            COMMON /INGEN/ GRL,IGEN,NUMGEN,NG(24)
            COMMON /SPECS/ PERX(13),WATJY(13),EXY(13),RADY(13),BHPX(13),
           $   BHPY(13),ESY(13),LHVY(13),BHPT(13),RADT(13),EXHT(13),KWLOAD(13)
           $  ,FUCON(13),BNBFC(13),BNBEX(13),BNBWH(13),DFCONY(13),QRCY(13),
           $   LOY(13),BTFCON(13),BTEXHT(13),WAUK(13),WAUKGR(13),WAUKLO(13),
           $   NBFCON(13),NBEXT(13),NBWJ(13),NBLD(13),NBCFC(13),NBCEX(13),
```

```
     $   NBCWJ(13),NBCLO(13),FMSFC(13),FMWJ(13),FMEX(13),FMLO(13),
     $   CATSFC(13),CATHG(13),CATLO(13),C315FC(13),C315LO(13),C315EH(13)
     $   ,F968EX(13),F968LO(13),F968WJ(13),F968FC(13),GKW(12)
      DIMENSION INUM(24),ITITL1(8),ITITL2(6),STKW(24),DATA(624),DUM(10)
      EQUIVALENCE (STO(2),STKW),(STO(2),DATA),(DUM,STOMAXH),(STKWLST,
     $   PCTIFIL)
      DATA INUM/6H 1 AM ,6H 2 AM ,6H 3 AM ,6H 4 AM ,6H 5 AM ,6H 6 AM ,
     $            6H 7 AM ,6H 8 AM ,6H 9 AM ,6H10 AM ,6H11 AM ,6H NOON ,
     $            6H 1 PM ,6H 2 PM ,6H 3 PM ,6H 4 PM ,6H 5 PM ,6H 6 PM ,
     $            6H 7 PM ,6H 8 PM ,6H 9 PM ,6H10 PM ,6H11 PM ,6HMD-NT /
C
C     READ AND ECHO INPUT DATA
C
      READ 1800, ITITL1
      PRINT 1900, ITITL1
      READ 1805, MODESTO,IGEN,NUMGEN
      READ 1810, FV,BEFF,COPA,COPC,TLO,THOT,TWS
      PRINT 1905, MODESTO,IGEN,NUMGEN,FV,BEFF,COPA,COPC,TLO,THOT,TWS
      IF (IGEN.LE.0 .OR. MODESTO.GT.4)  GO TO 9995
      GPL=GKW(IGEN)
      GO TO (155,20,30,30) MODESTO
C------------ READ DATA FOR THERMAL STORAGE ANALYSIS
   20 READ 1810, STOMAXH,STOMAXC,QINMAXH,QOTMAXH,TNINMAX,TNOTMAX,TONCMAX
      READ 1810, PCTIFIL,PCTLSTH,PCTLSTC
      PRINT 1910, STOMAXH,STOMAXC,QINMAXH,QOTMAXH,TNINMAX,TNOTMAX,
     $            TONCMAX,PCTIFIL,PCTLSTH,PCTLSTC
      GO TO 155
C------------ READ DATA FOR ELECTRICAL STORAGE ANALYSIS
   30 READ 1810, (DUM(I), I=1,7)
      PRINT 1915, (DUM(I), I=1,7)
      GO TO 155
C------------ BUFFER-OUT DATA FROM PREVIOUS DAY TO TAPE1 FOR PLOTTING
  140 BUFFER OUT (1,0) (DATA(1),DATA(624))
      IF (UNIT(1)) 145,9999,9993
  145 PRINT 1900, ITITL1
      GO TO 155
C------------ CHECK FOR ABILITY TO PROCEED AFTER ERROR
  150 IF (IDAY.GT.0)  GO TO 9993
      PRINT 1900, ITITL1
C------------ READ DAILY LOADS FOR EACH HOUR OF DAY
  155 READ 1815, IDAY,ISESON,I,ITITL2
      IF (EOF(50)) 9999,170
  170 PRINT 1920, ITITL2,IDAY,ISESON,I
      IF (I.GT.0)  GO TO 185
      IF (MODESTO.NE.4)  GO TO 180
      READ 1810, GENAVG
      PRINT 1921, GENAVG
  180 READ 1810, QHWD
      READ 1810, SHEJD
      READ 1810, TOND
      READ 1810, DEKW
      READ 1810, AUXKW
      READ 1810, OQPCJ
```

```
  185 PRINT 1925
      DO 190 I=1,24
      PRINT 1926, INUM(I),QHWD(I),SHETD(I),TOND(I),DEKW(I),AUXKW(I),
     *       OQPOV(I)
      DED(I)=DEKW(I)+AUXKW(I)
  190 CONTINUE
      DRFUEL=0.0
      DPMFUEL=0.0
      DTONA=0.0
      DTONC=0.0
      DCED=0.0
      DGENKW=0.0
      DTORCV=0.0
      DOWSTD=0.0
      GO TO (200,400,600,700) MODESTO
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C          NO ENERGY STORAGE OPTION  (MODESTO=1)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
  200 PRINT 1950, TTITL2
      PRINT 1951
  205 DO 300 I=1,24
      CED(I)=0.0
      CEDOLD=0.0
C............ CALCULATE GENERATOR LOADS AND AVAILABLE ABSORPTION A/C
      GENKW(I)=DED(I)
      CALL HEAT(I)
      TONAA=QAABS(I)*COPA/12000.0
      TONNED=TOND(I)-TONAA
      IF (TONNED .LE. 0.0)  GO TO 270
C............ IF ABS A/C IS INSUFFICIENT, FIND ITERATIVE SOLUTION TO
C............   COMP A/C, GENERATOR LOADS, AND ABS A/C BALANCE
      CED(I)=TONNED/COPC*3.515
      ITER=1
  210 GENKW(I)=DED(I)+CED(I)
      CALL HEAT(I)
      TONC(I)=CED(I)*COPC/3.515
      QABS(I)=QAABS(I)
      TONA(I)=QABS(I)*COPA/12000.0
      DELTA=TOND(I)-(TONA(I)+TONC(I))
      IF (ABS(DELTA) .LT. 2.0)  GO TO 260
      IF (DELTA) 230,250,240
  230 CEDNEW=CED(I)-0.5*ABS(CED(I)-CEDOLD)
      CEDOLD=CED(I)
      CED(I)=CEDNEW
      GO TO 250
  240 CEDNEW=CED(I)+0.5*ABS(CED(I)-CEDOLD)
      CEDOLD=CED(I)
      CED(I)=CEDNEW
  250 ITER=ITER+1
      IF (ITER.LL.25)  GO TO 210
      PRINT 1991, I,DELTA,CEDOLD,CEDNEW,TONC(I)
      GO TO 150
  260 QWSTD(I)=QOILA(I)
```

```
      GO TO 280
C............ ABS A/C IS SUFFICIENT, CALCULATE HEAT WASTED
  270 TONA(I)=TOND(I)
      TONC(I)=0.0
      QABS(I)=TONA(I)/COPA*12000.0
      QWSTO(I)=QAABS(I)-QABS(I)+QOILA(I)
C............ CALCULATE FUEL USAGE AND DAILY TOTALS
  280 PMFUEL(I)=HRE(I)*GENKW(I)/FV
      BFUEL(I)=QBOIL(I)/(FV*BEFF)
      DPMFUEL=DPMFUEL+PMFUEL(I)
      DTONA=DTONA+TONA(I)
      DTONC=DTONC+TONC(I)
      DCED=DCED+CED(I)
      DGENKW=DGENKW+GENKW(I)
      DTQRCV=DTQRCV+TQRCV(I)
      IF (MODESTO.GT.1)  GO TO 300
      DBFUEL=DBFUEL+BFUEL(I)
      DQWSTO=DQWSTO+QWSTO(I)
      PRINT 1952, INUM(I),BFUEL(I),PMFUEL(I),(BFUEL(I)+PMFUEL(I)),
     $   TONA(I),TONC(I),CED(I),GENKW(I),TQRCV(I),QWSTO(I),NG(I)
  300 CONTINUE
      IF (MODESTO.EQ.2)  GO TO 405
      PRINT 1953
      PRINT 1954, DBFUEL,DPMFUEL,(DBFUEL+DPMFUEL),DTONA,DTONC,DCED,
     $               DGENKW,DTQRCV,DQWSTO
      PRINT 1931
      GO TO 140
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C      THERMAL ENERGY STORAGE OPTION  (MODESTO=2)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
  400 PRINT 1955, ITITL2
      GO TO (205,205,510,205) ISESON
C------------ WINTER, SPRING, AUTUMN  (HOT WATER STORAGE)
  405 PRINT 1956
      STO(I)=PCTIFIL*STOMAXH
      IF (IDAY.GT.1)  STO(1)=STOLAST
      QLOST=PCTLSTH*STOMAXH
      DO 460 I=1,24
      QIN=QWSTO(I)-QOILA(I)
      IF (QIN .GT. QINMAXH)  QIN=QINMAXH
      QOUT=QBOIL(I)
      IF (QOUT .GT. QOTMAXH)  QOUT=QOTMAXH
      STO(I+1)=STO(I)+QIN-(QOUT+QLOST)
      IF (STO(I+1) .GT. STOMAXH)  GO TO 420
      IF (STO(I+1) .LT. 0.0)  GO TO 435
      QWSTO(I)=QWSTO(I)-QIN
      QBOIL(I)=QBOIL(I)-QOUT
      GO TO 450
  420 STO(I+1)=STOMAXH
      QIN=STOMAXH-STO(I)
      QWSTO(I)=QWSTO(I)-QIN
      QBOIL(I)=QBOIL(I)-QOUT
      GO TO 450
```

```
  435 STO(I+1)=0.0
      QOUT=STO(I)
      QWSTO(I)=QWSTO(I)-QIN
      QBOIL(I)=QBOIL(I)-QOUT
  450 DQWSTO=DQWSTO+QWSTO(I)
      BFUEL(I)=QBOIL(I)/(FV*BEFF)
      DBFUEL=DBFUEL+BFUEL(I)
      PRINT 1957, INUM(I),BFUEL(I),PMFUEL(I),TONA(I),TONC(I),CED(I),
     $            GENKW(I),TQRCV(I),QWSTO(I),STO(I+1),NG(I)
  460 CONTINUE
      PRINT 1958
      PRINT 1959, DBFUEL,DPMFUEL,DTONA,DTONC,DCED,DGENKW,DTQRCV,DQWSTO
      PRINT 1901
      PRINT 1902
      STOLAST=STO(25)
      GO TO 140
C------------ SUMMER  (COLD WATER STORAGE)
  500 PRINT 1960
      STO(1)=PCTIFIL*STOMAXC
      IF (IDAY.GT.1)  STO(1)=STOLAST
      DO 590 I=1,24
      ITER=0
      CEDOLD=0.0
      CED(I)=TONCMAX/COPC*3.515
C............. FIND ITERATIVE SOLUTION TO COMP A/C, GENERATOR LOADS, AND
C.............   ABS A/C BALANCE
  510 GENKW(I)=CED(I)+DED(I)
      IF (GENKW(I) .LE. (GRL*NUMGEN))  GO TO 515
      GENKW(I)=GRL*NUMGEN
      IF (DED(I) .GT. GENKW(I))  GENKW(I)=DED(I)
      CED(I)=GENKW(I)-DED(I)
      IF (CED(I) .LT. 1.0)  CED(I)=0.0
  515 CALL HEAT(I)
      TONA(I)=QAABS(I)*COPA/12000.0
      TONC(I)=CED(I)*COPC/3.515
      IF (ITER.GT.0)  GO TO 550
C............. CALCULATE ENERGY FLOW INTO/OUT OF STORAGE
      TONIN=TONA(I)+TONC(I)-TOND(I)
      IF (TONIN .GT. TNINMAX)  TONIN=TNINMAX
      IF (TONIN .LT. (-TNOTMAX))  TONIN=-TNOTMAX
      STO(I+1)=STO(I)+TONIN-PCTLSTC*STOMAXC
      IF (STO(I+1) .LT. 0.0)  GO TO 540
      IF (STO(I+1) .LE. STOMAXC)  GO TO 550
      TONIN=STOMAXC-STO(I)
      STO(I+1)=STO(I)+TONIN-PCTLSTC*STOMAXC
      GO TO 550
  540 TONIN=-STO(I)
      STO(I+1)=0.0
  550 IF (CED(I) .LE. 1.0)  GO TO 570
      DELTA=TOND(I)+TONIN-(TONA(I)+TONC(I))
      IF (ABS(DELTA) .LT. 2.0)  GO TO 580
      IF (DELTA) 555,580,560
  555 CEDNEW=CED(I)-0.5*ABS(CED(I)-CEDOLD)
```

```
      CEDOLD=CED(I)
      CED(I)=CEDNEW
      GO TO 565
  560 CEDNEW=CED(I)+0.5*ABS(CED(I)-CEDOLD)
      CEDOLD=CED(I)
      CED(I)=CEDNEW
  565 IF (CED(I) .LT. 0.0)  CED(I)=0.0
      ITER=ITER+1
      IF (ITER.LE.25)  GO TO 510
      PRINT 1991, 2,DELTA,CEDOLD,CEDNEW,TONIN
      GO TO 150
  570 TONA(I)=TONO(I)+TONIN
      QABS(I)=TONA(I)/COPA*12000.0
      QWSTO(I)=QAABS(I)-QABS(I)
      IF(QWSTO(I).GT.-1.) GO TO 575
      PRINT 1995, QWSTO(I)
      GO TO 150
  575 QWSTO(I)=QWSTO(I)+QOILA(I)
      TONC(I)=0.0
      CED(I)=0.0
      GO TO 585
  580 QWSTO(I)=QOILA(I)
  585 PMFUEL(I)=HRE(I)*GENKW(I)/FV
      BFUEL(I)=QBOIL(I)/(FV*BEFF)
      DBFUEL=DBFUEL+BFUEL(I)
      DPMFUEL=DPMFUEL+PMFUEL(I)
      DTONA=DTONA+TONA(I)
      DTONC=DTONC+TONC(I)
      DCED=DCED+CED(I)
      DGENKW=DGENKW+GENKW(I)
      DTQRCV=DTQRCV+TQRCV(I)
      DQWSTO=DQWSTO+QWSTO(I)
      PRINT 1961, INUM(I),BFUEL(I),PMFUEL(I),TONA(I),TONC(I),CED(I),
     $            GENKW(I),TQRCV(I),QWSTO(I),STO(I+1),NG(I)
  590 CONTINUE
      PRINT 1958
      PRINT 1959, DBFUEL,DPMFUEL,DTONA,DTONC,DCED,DGENKW,DTQRCV,DQWSTO
      PRINT 1931
      STOLAST=STO(25)
      GO TO 140
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C         ELECTRICAL ENERGY STORAGE OPTION  (MODESTO=3)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
  600 PRINT 1965, ITIT_2
      PRINT 1951
      DO 680 I=1,24
      GENKW(I)=GPL*NUMGEN
      CALL HEAT(I)
      TONAA=QAABS(I)*COPA/12000.0
      DELTA=TONO(I)-TONAA
      IF (DELTA .GE. 0.0)  GO TO 650
      ITER=0
      GENOLD=GENKW(I)
```

```
      GENKW(I)=0.5*GENOLD
C............ FIND MAX GEN OUTPUT AT WHICH ALL WASTE HEAT CAN BE USED
  615 CALL HEAT(I)
      TONAA=QAABS(I)*COPA/12000.0
      DELTA=TOND(I)-TONAA
      IF (ABS(DELTA+1.0) .LT. 1.0)  GO TO 650
      IF (DELTA+1.0)  620,650,625
  620 GENNEW=GENKW(I)-0.5*ABS(GENKW(I)-GENOLD)
      GENOLD=GENKW(I)
      GENKW(I)=GENNEW
      GO TO 630
  625 GENNEW=GENKW(I)+0.5*ABS(GENKW(I)-GENOLD)
      GENOLD=GENKW(I)
      GENKW(I)=GENNEW
  630 IF (GENKW(I) .LT. 1.0)  GO TO 640
      ITER=ITER+1
      IF (ITER.LE.25)  GO TO 615
      PRINT 1991, 3,DELTA,GENOLD,GENNEW
      GO TO 150
  640 GENKW(I)=1.0
      CALL HEAT(I)
      QABS(I)=TOND(I)/COPA*12000.0
      TONA(I)=TOND(I)
      TONC(I)=0.0
      GO TO 660
  650 TONA(I)=TONAA
      QABS(I)=QAABS(I)
      TONC(I)=TOND(I)-TONA(I)
      IF (TONC(I) .LT. 0.0)  TONC(I)=0.0
  660 CALL ELECSTO(I,IDAY)
      IF (IDAY.GE.0)  GO TO 670
      PRINT 1991, 4,DUM(9),GENKW(I)
      GO TO 150
  670 PRINT 1952, INUM(I),BFUEL(I),PMFUEL(I),(BFUEL(I)+PMFUEL(I)),
     $   TONA(I),TONC(I),CED(I),GENKW(I),TQRCV(I),QWSTD(I),NG(I)
  680 CONTINUE
      PRINT 1953
      PRINT 1954, DBFUEL,DPMFUEL,(DBFUEL+DPMFUEL),DTONA,DTONC,DCED,
     $   DGENKW,DTQRCV,DQWSTD
      PRINT 1901
      PRINT 1956
      DO 690 I=1,24
      PRINT 1957, INUM(I),DED(I),CED(I),SED(I),GENKW(I),STKW(I)
  690 CONTINUE
      STKWLST=STKW(24)
      GO TO 140
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C        CONSTANT LOAD ELECTRICAL ENERGY STORAGE OPTION  (MODESTO=4)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
  700 PRINT 1958, ITITL2
      PRINT 1951
      DO 760 I=1,24
      GENKW(I)=GENAVG
```

```
                CALL HEAT(I)
                TONA(I)=QAABS(I)*COPA/12000.0
                TONC(I)=TOND(I)-TONA(I)
                IF (TONC(I) .GE. 0.0)  GO TO 720
                TONC(I)=0.0
                TONA(I)=TOND(I)
            720 QABS(I)=TONA(I)/COPA*12000.0
                CALL ELECSTO(I,IDAY)
                IF (IDAY.GE.0)  GO TO 740
                PRINT 1991, 5,DUM(9),GENKW(I)
                GO TO 150
            740 PRINT 1952, INUM(I),BFUEL(I),PMFUEL(I),(BFUEL(I)+PMFUEL(I)),
               $   TONA(I),TONC(I),CED(I),GENKW(I),TQRCV(I),QHSTD(I),NG(I)
            760 CONTINUE
                PRINT 1953
                PRINT 1954, DBFUEL,DPMFUEL,(DBFUEL+DPMFUEL),DTONA,DTONC,DCED,
               $   DGENKW,DTQRCV,DQHSTD
                PRINT 1991
                PRINT 1966
                DO 770 I=1,24
                PRINT 1967, INUM(I),DED(I),CED(I),SED(I),GENKW(I),STKW(I)
            770 CONTINUE
                STKWLST=STKW(24)
                GO TO 140
          C
           9990 PRINT 1992
                STOP 01
           9995 PRINT 1993
                STOP 02
           9999 STOP
          C
           1800 FORMAT(8A10)
           1805 FORMAT(16I5)
           1810 FORMAT(8E10.0)
           1815 FORMAT(3I5,5X,6A10)
           1900 FORMAT(1H1,16X≠*********** ≠,8A10,≠ ***********≠)
           1901 FORMAT(≠-≠/≠-≠5X≠*   MILLIONS OF BTU PER HOUR≠)
           1902 FORMAT(≠0≠5X≠**  MILLIONS OF BTU≠)
           1905 FORMAT(1H-,4X≠MODESTO≠9X≠IGEN≠7X≠NUMGEN≠12X≠FV≠12X≠BEFF≠9X≠COPA≠
               $   9X≠COPC≠9X≠TLO≠9X≠THOT≠10X≠THS≠/46X≠(BTU/GAL)≠38X,3(10X≠(F)≠)/
               $   7X,I5,2(8X,I5),8X,F9.0,3(4X,F9.3),3(4X,F9.2))
           1910 FORMAT(1H-,4X≠STOMAXH≠6X≠STOMAXC≠6X≠QINMAXH≠6X≠QOTMAXH≠7X≠TNINMAX≠
               $   6X≠TNOTMAX≠6X≠TONCMAX≠7X≠PCTIFIL≠5X≠PCTLSTH≠5X≠PCTLSTC≠/6X
               $   ≠(BTU)≠5X≠(TON-HOURS)≠3X≠(BTU/HR)≠5X≠(BTU/HR)≠1X,3(7X≠(TONS)≠)/
               $   4(3X,1PE10.3),3(7X,0PF5.1),3(8X,F5.3))
           1915 FORMAT(1H-,4X≠SEDMAXC≠6X≠SEDMAXD≠6X≠STKWMAX≠7X≠STPCIN≠7X≠EFFCHG≠7X
               $   ≠EFFSBY≠7X≠EFFDIS≠/7X≠(KW)≠9X≠(KW)≠8X≠(KWH)≠/3X,F9.1,2(4X,F9.1),
               $   4(4X,F9.3))
           1920 FORMAT(≠-≠/≠-HOURLY INPUT DATA FOR ≠6A10/1H0,10X≠IDAY =≠I5,5X
               $   ≠ISLSUN =≠I5,5X≠I =≠I5)
           1921 FORMAT(11X≠GENAVG =≠F10.2≠ KW≠)
           1925 FORMAT(1H-,15X≠DOMESTIC HOT≠5X≠SPACE HEATING≠6X≠AIR COND.≠8X
               $   ≠DOMESTIC≠9X≠AUXILIARY≠8X≠OTHER HEAT≠/6X≠HOUR≠6X≠WATER DEMAND≠
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     $    8X≠DEMAND≠11X≠DEMAND≠8X≠ELECT DEMAND≠5X≠ELECT DEMAND≠7X
     $    ≠RECOVERED≠/18X≠(BTU/HR)≠3X≠(BTU/HR)≠10X≠(TONS)≠12X≠(KW)≠13X
     $    ≠(KW)≠12X≠(BTU/HR)≠/)
 1926 FORMAT(5X,A6,6(5X,1PE12.5))
 1950 FORMAT(≠1OUTPUT FOR ≠,6A10,10X≠<NO STORAGE OPTION>≠)
 1951 FORMAT(1H-,12X≠BOILER≠5X≠PRIME MOVER≠5X≠TOTAL≠7X≠ABSORPTION≠3X
     $    ≠COMPRESSION≠4X≠ELECT FOR≠4X≠GENERATOR≠5X≠TOTAL H.G.≠5X≠WASTED≠
     $    4X≠NO.≠/3X≠HOUR≠1X,3(4X≠FUEL REQD≠),2(6X≠AIR COND≠),6X
     $    ≠COMP A/C≠4X≠SET OUTPUT≠4X≠HEAT RECOV≠6X≠HEAT≠5X≠GEN≠/7X,
     $    3(5X≠(GAL/HR)≠),2(8X≠(TONS)≠),2(9X≠(KW)≠),2(10X≠(*)≠)/)
 1952 FORMAT(2X,A5,5X,F7.1,2(6X,F7.1),1X,3(7X,F7.1),6X,F7.1,1X,
     $    2(6X,-6PF7.3),3X,I3)
 1953 FORMAT(6X,3(5X≠---------≠),1X,3(5X≠---------≠),5X≠---------≠1X,
     $    2(5X≠---------≠))
 1954 FORMAT(2X≠TOTAL≠4X,F8.1,2(5X,F8.1),1X,3(6X,F8.1),4X,F9.1,1X,
     $    2(5X,-6PF8.3))
 1955 FORMAT(≠1OUTPUT FOR ≠,6A10,10X≠<THERMAL STORAGE OPTION>≠)
 1956 FORMAT(1H-,12X≠BOILER≠5X≠PRIME MOVER≠4X≠ABSORPTION≠3X≠COMPRESSION≠
     $    4X≠ELECT FOR≠4X≠GENERATOR≠5X≠TOTAL H.G.≠5X≠WASTED≠5X≠ENERGY IN≠
     $    4X≠NO.≠/3X≠HOUR≠1X,2(4X≠FUEL REQD≠),2(6X≠AIR COND≠),6X
     $    ≠COMP A/C≠4X≠SET OUTPUT≠4X≠HEAT RECOV≠6X≠HEAT≠7X≠STORAGE≠5X
     $    ≠GEN≠/7X,2(5X≠(GAL/HR)≠),2(8X≠(TONS)≠),2(9X≠(KW)≠),2(10X≠(*)≠),
     $    10X≠(**)≠/)
 1957 FORMAT(2X,A5,5X,F7.1,6X,F7.1,1X,3(7X,F7.1),5X,F7.1,1X,
     $    3(6X,-6PF7.3),4X,I3)
 1958 FORMAT(6X,2(5X≠---------≠),1X,3(5X≠---------≠),5X≠---------≠1X,
     $    2(5X≠---------≠))
 1959 FORMAT(2X≠TOTAL≠4X,F8.1,5X,F8.1,1X,3(6X,F8.1),4X,F9.1,1X,
     $    2(5X,-6PF8.3))
 1960 FORMAT(1H-,12X≠BOILER≠5X≠PRIME MOVER≠4X≠ABSORPTION≠3X≠COMPRESSION≠
     $    4X≠ELECT FOR≠4X≠GENERATOR≠5X≠TOTAL H.G.≠5X≠WASTED≠5X≠ENERGY IN≠
     $    4X≠NO.≠/3X≠HOUR≠1X,2(4X≠FUEL REQD≠),2(6X≠AIR COND≠),6X
     $    ≠COMP A/C≠4X≠SET OUTPUT≠4X≠HEAT RECOV≠6X≠HEAT≠7X≠STORAGE≠5X
     $    ≠GEN≠/7X,2(5X≠(GAL/HR)≠),2(8X≠(TONS)≠),2(9X≠(KW)≠),2(10X≠(*)≠),
     $    8X≠(TON-HR)≠/)
 1961 FORMAT(2X,A5,5X,F7.1,6X,F7.1,1X,3(7X,F7.1),5X,F7.1,1X,
     $    2(6X,-6PF7.3),6X,0PF7.1,4X,I3)
 1965 FORMAT(≠1OUTPUT FOR ≠,6A10,10X≠<ELECTRICAL STORAGE OPTION>≠)
 1966 FORMAT(1H1,12X≠DOMESTIC≠5X≠COMPRESSION≠5X≠STORAGE≠5X≠GENERATOR≠4X
     $    ≠ENERGY IN≠/3X≠HOUR≠2X,3(3X≠ELEC DEMAND≠),3X≠SET OUTPUT≠4X
     $    ≠STORAGE≠/5X,3(10X≠(KW)≠),9X≠(KW)≠9X≠(KWH)≠/)
 1967 FORMAT(2X,A5,7X,F7.1,2(7X,F7.1),2(5X,F8.1))
 1968 FORMAT(≠1OUTPUT FOR ≠,6A10,10X≠<CONSTANT LOAD ELECTRICAL STORAGE ≠
     $    ≠OPTION>≠)
 1991 FORMAT(≠-===== ERROR -- MORE THAN 25 ITERATIONS REQUIRED =====≠/
     $    5X,I5,4(5X,1PE10.3))
 1992 FORMAT(≠-========== ERROR IN BUFFER-OUT OPERATION ==========≠)
 1993 FORMAT(≠-========== ERROR IN INPUT ==========≠)
 1995 FORMAT(≠-===== ERROR - INSUFFICIENT COOLING CAPACITY =====≠/
     $    10X≠QWSTO = ≠1PE10.3≠ BTU/HR≠)
      END
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      SUBROUTINE HEAT(I)
C
C       SUBROUTINE HEAT CALCULATES THE HEAT AVAILABLE FOR ABSORPTION
C        A/C AFTER SATISFYING HOT WATER AND SPACE HEATING REQUIREMENTS
C
      COMMON /IN/ STO(25),QBOIL(24),QAABS(24),OQRCV(24),QHWD(24),
     $   QOILW(24),QOILA(24),PMQRCV(24),QHWAO(24),TQRCV(24),QABS(24),
     $   QWSTD(24),OILCQ(24),PMFUEL(24),BFUEL(24),CED(24),DED(24),
     $   TONA(24),TONC(24),TOND(24),SHETD(24),HRE(24),AUXKW(24),DEKW(24)
     $  ,GENKW(24),SED(24),TLO,THOT,TWS
C
      CALL GENRAT(GENKW,PMQRCV,HRE,I,OILCQ)
      TQRCV(I)=PMQRCV(I)+OQRCV(I)
      IF (TLO .GT. (THOT+10.0))  GO TO 20
      QCHK=QHWD(I)/(THOT-TWS)*(TLO-10.0-TWS)
      IF(OILCQ(I).LT.QCHK) GO TO 10
      QHWAO(I)=QHWD(I)-QCHK
      QOILW(I)=QCHK
      QOILA(I)=OILCQ(I)-QOILW(I)
      GO TO 60
   10 QOILA(I)=0.0
      QHWAO(I)=QHWD(I)-OILCQ(I)
      GO TO 60
   20 QHWAO(I)=QHWD(I)-OILCQ(I)
      IF(QHWAO(I)) 40,30,30
   30 QOILA(I)=0.0
      QOILW(I)=OILCQ(I)
      GO TO 60
   40 QNSP=SHETD(I)+QHWAO(I)
      IF(QNSP) 50,50,90
   50 QOILW(I)=QHWD(I)+SHETD(I)
      QOILA(I)=-QNSP
      QAABS(I)=TQRCV(I)
      QBOIL(I)=0.0
      GO TO 120
   60 QREM=TQRCV(I)-QHWAO(I)
      QNED=SHETD(I)-QREM
      IF(QNED) 70,70,80
   70 QAABS(I)=-QNED
      QBOIL(I)=0.0
      GO TO 120
   80 QBOIL(I)=QNED
      QAABS(I)=0.0
      GO TO 120
   90 QREM=TQRCV(I)-QNSP
      QOILW(I)=OILCQ(I)
      QOILA(I)=0.0
      IF(QREM) 110,100,100
  100 QAABS(I)=QREM
      QBOIL(I)=0.0
      GO TO 120
  110 QBOIL(I)=-QREM
      QAABS(I)=0.0
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      120 RETURN
          END
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      SUBROUTINE GENRAT(KW,QRC,HRE,I,OILCQ)
C
C        SUBROUTINE GENRAT CALCULATES PRIME MOVER FUEL REQUIREMENTS AND
C         WASTE HEAT RECOVERY GIVEN THE ELECTRICAL DEMAND (KW)
C
      COMMON /INGEN/ GRL,IGEN,NUMGEN,NG(24)
      COMMON /SPECS/ PERX(13),WATJY(13),EXY(13),RADY(13),BHPX(13),
     $   BHFY(13),EGY(13),LHVY(13),BHPT(13),RADT(13),EXHT(13),KWLOAD(13)
     $  ,FUCON(13),BNBFC(13),BNBEX(13),BNBWH(13),DFCONY(13),ORCY(13),
     $   LOY(13),BTFCON(13),BTEXHT(13),WAUK(13),WAUKOR(13),WAUKLO(13),
     $   NBFCON(13),NBEXT(13),NBWJ(13),NBLO(13),NBCFC(13),NBCEX(13),
     $   NBCWJ(13),NBCLO(13),FMSFC(13),FMWJ(13),FMEX(13),FMLO(13),
     $   CATSFC(13),CATHG(13),CATLO(13),C315FC(13),C315LO(13),C315EW(13)
     $  ,F968EX(13),F968LO(13),F968WJ(13),F968FC(13),SKW(12)
      DIMENSION KW(24),HRE(24),OILCQ(24),QRC(24)
      REAL KWLOAD,LHVY,LOY,NBCEX,NBCFC,NBCLO,NBCWJ,NBEXT,NBFCON,NBLO,
     $     NBWJ,KW
C
      NG(I)=KW(I)/GRL+0.999
      IF (NG(I).GT.0)  GO TO 5
      PRINT 900, NG(I)
      STOP 11
    5 IF (NG(I) .GT. NUMGEN)  NG(I)=NUMGEN
      GLOAD=KW(I)/NG(I)
      PERRL=GLOAD/GRL
      IF (PERRL .GT. 1.20)  GO TO 790
      GO TO (10,20,30,40,50,60,70,80,90,100,110,120) IGEN
C------------ 1540 KW NORDBERG DIESEL
   10 CALL INTERP(PERX,DFCONY,PERRL,HRE(I))
      CALL INTERP(PERX,ORCY,PERRL,Y)
      QRC(I)=Y*NG(I)*1000000.
      CALL INTERP(PERX,LOY,PERRL,Y)
      OILCQ(I)=Y*NG(I)*1000000.0
      RETURN
C------------ 425 KW WAUKESHA DIESEL
   20 CALL INTERP(PERX,WAUK,PERRL,Y)
      HRE(I)=Y*1000.
      CALL INTERP(PERX,WAUKOR,PERRL,Y)
      QRC(I)=Y*NG(I)*1000000.0
      CALL INTERP(PERX,WAUKLO,PERRL,Y)
      OILCQ(I)=Y*NG(I)*1000000.0
      RETURN
C------------ 2200 KW NORDBERG DIESEL
   30 CALL INTERP(PERX,BNBFC,PERRL,HRE(I))
      CALL INTERP(PERX,BNBEX,PERRL,Y)
      QRC(I)=Y*NG(I)*1000000.0
      CALL INTERP(PERX,BNBWH,PERRL,Y)
      OILCQ(I)=Y*NG(I)*2860000.0
      RETURN
C------------ 1750 KW NORDBERG DIESEL
   40 CALL INTERP(PERX,NBFCON,PERRL,HRE(I))
      CALL INTERP(PERX,NBEXT,PERRL,Y)
      QRC(I)=Y*NG(I)*1000000.0
```

```
      CALL INTERP(PERX,NBWJ,PERRL,X)
      CALL INTERP(PERX,NBLO,PERRL,Y)
      OILCQ(I)=(X+Y)*NG(I)*1000000.0
      RETURN
C------------ 4415 KW NORDBERG DIESEL
   50 CALL INTERP(PERX,NBCFC,PERRL,HRE(I))
      CALL INTERP(PERX,NBCEX,PERRL,Y)
      QRC(I)=Y*NG(I)*1000000.0
      CALL INTERP(PERX,NBCWJ,PERRL,X)
      CALL INTERP(PERX,NBCLO,PERRL,Y)
      OILCQ(I)=(X+Y)*NG(I)*1000000.0
      RETURN
C------------ 478 KW FAIRBANKS-MORSE DIESEL
   60 CALL INTERP(PERX,FMSFC,PERRL,HRE(I))
      CALL INTERP(PERX,FMEX,PERRL,X)
      CALL INTERP(PERX,FMWJ,PERRL,Y)
      QRC(I)=(X+Y)*NG(I)*1000000.0
      CALL INTERP(PERX,FMLO,PERRL,Y)
      OILCQ(I)=Y*NG(I)*1000000.0
      RETURN
C------------ 475 KW CATERPILLAR DIESEL
   70 CALL INTERP(PERX,CATSFC,PERRL,HRE(I))
      CALL INTERP(PERX,CATHS,PERRL,Y)
      QRC(I)=Y*NG(I)*1000000.0
      CALL INTERP(PERX,CATLO,PERRL,Y)
      OILCQ(I)=Y*NG(I)*1000000.0
      RETURN
C------------ 500 KW WAUKESHA DIESEL
   80 CALL INTERP(PERX,EGY,PERRL,Y)
      PO=GLOAD/(Y*0.745)
      PERFL=GLOAD/(Y*GRL)
      CALL INTERP(BHPX,LHVY,PO,Y)
      QIN=Y*PO
      CALL INTERP(PERX,WATJY,PERFL,POWJ)
      CALL INTERP(PERX,BHPY,PERFL,PBHP)
      CALL INTERP(PERX,EXY,PERFL,PEX)
      CALL INTERP(PERX,RADY,PERFL,PRAD)
      PLO=1.0-(POWJ+PBHP+PEX+PRAD)
      X=POWJ*QIN*NG(I)
      Y=PEX*QIN*NG(I)
      OILCQ(I)=PLO*QIN*NG(I)
      QRC(I)=X+0.55*Y
      HRE(I)=QIN/KW(I)
      RETURN
C------------ 315 KW CATERPILLAR DIESEL
   90 CALL INTERP(PERX,C315FC,PERRL,HRE(I))
      CALL INTERP(PERX,C315EX,PERRL,Y)
      QRC(I)=Y*NG(I)*1000000.0
      CALL INTERP(PERX,C315LO,PERRL,Y)
      OILCQ(I)=Y*NG(I)*1000000.0
      RETURN
C------------ 968 KW FAIRBANKS-MORSE DIESEL
  100 CALL INTERP(PERX,F968FC,PERRL,HRE(I))
```

```
      CALL INTERP(PERX,F968EX,PERRL,X)
      CALL INTERP(PERX,F958WJ,PERRL,Y)
      QRC(I)=(X+Y)*NG(I)*1000000.0
      CALL INTERP(PERX,F968LO,PERRL,Y)
      OTLCO(I)=Y*NG(I)*1000000.0
      RETURN
C------------ 400 KW AIRESEARCH TURBINE
  110 CALL INTERP(PERX,EXHT,PERRL,X)
      CALL INTERP(PERX,RADT,PERRL,RAD)
      CALL INTERP(PERX,BHPT,PERRL,BHP)
      CALL INTERP(KWLOAD,FUCON,GLOAD,Y)
      QIN=Y*NG(I)
      QRC(I)=X*QIN*0.55
      OTLCO(I)=QIN*(1.0-(X+RAD+BHP))
      HRE(I)=QIN/KW(I)
      RETURN
C------------ 1200 KW N.A. TURBINE
  120 CALL INTERP(PERX,BTFCON,PERRL,HRE(I))
      CALL INTERP(PERX,BTEXHT,PERRL,Y)
      QRC(I)=Y*NG(I)*1000000.0
      OTLCO(I)=0.10*NG(I)*1000000.0
      RETURN
C
  790 PRINT 910, NG(I),PERRL
      STOP 12
C
  900 FORMAT(≠-***** ERROR IN NG =≠I3≠ *****≠)
  910 FORMAT(≠-*****≠I3≠ GENERATORS OPERATING OVER 120% OF RATED LOAD ≠
     $ ≠-- PERRL =≠F5.2≠ *****≠)
      END
```

```
      SUBROUTINE INTERP(X,Y,XE,YE)
C
C        SUBROUTINE INTERP IS USED TO LINEARLY INTERPOLATE BETWEEN
C          VALUES IN TWO ARRAYS (X AND Y) TO FIND THE VALUE YE AT XE
C
      DIMENSION X(13),Y(13)
      IF(XE.GE.X(1)) GO TO 2
      PRINT 99
      YE=0.0
      GO TO 7
    2 J=2
    3 IF (XE-X(J))6,5,4
    4 J=J+1
      IF(J.LE.13) GO TO 3
    5 YE=Y(J)
      GO TO 7
    6 YE=Y(J-1)+(Y(J)-Y(J-1))/(X(J)-X(J-1))*(XE-X(J-1))
    7 RETURN
C
   99 FORMAT(*-***** THE INDEPENDENT VARIABLE IS OUT OF RANGE *****)
      END
```

```
      SUBROUTINE ELECSTO(I,IDAY)
      COMMON /IN/ STO(25),QBOIL(24),QAABS(24),OQRCV(24),QHWD(24),
     $   OOTLW(24),QOILA(24),PMIRCV(24),OHWAO(24),TQRCV(24),OABS(24),
     *   QWSTD(24),OILDQ(24),PMFUEL(24),BFUEL(24),CED(24),DED(24),
     $   TONA(24),TONC(24),TOND(24),SHETD(24),HRE(24),AUXKW(24),DEKW(24)
     $  ,GENKW(24),SED(24),TLO,THOT,TWS
      COMMON /MISC/ FV,BEFF,COPA,COPC,DBFUEL,DPMFUEL,DTONA,DTONC,DCED,
     $   DGENKW,DTQRCV,DQWSTD,SEDMAXC,SEDMAXD,STKWMAX,STPCIN,EFFCHG,
     $   EFFSBY,EFFDIS,STKWLST,GENLOAD,OUM1
      DIMENSION STKW(24)
      EQUIVALENCE (STO(2),STKW)
C
C      CALCULATE STORAGE CHARGE/DISCHARGE RATE AND AMOUNT OF ENERGY
C        IN STORAGE
C
      CED(I)=TONC(I)/COPC*3.515
      SED(I)=GENKW(I)-(DED(I)+CED(I))
      IF (SED(I) .GT. SEDMAXC)  SED(I)=SEDMAXC
      IF (SED(I) .LT. (-SEDMAXD))  SED(I)=-SEDMAXD
      IF (I.GT.1)  GO TO 120
      IF (IDAY.GT.1)  GO TO 110
      STOREKW=STPCIN*STKWMAX
      GO TO 130
  110 STOREKW=STKWLST
      GO TO 130
  120 STOREKW=STKW(I-1)
  130 IF (SED(I)) 140,150,150
C............ DISCHARGE
  140 STKW(I)=EFFSBY*STOREKW+SED(I)/EFFDIS
      IF (STKW(I) .GE. 0.0)  GO TO 160
      STKW(I)=0.0
      SED(I)=-EFFSBY*EFFDIS*STOREKW
      GO TO 160
C............ CHARGE
  150 STKW(I)=EFFSBY*STOREKW+EFFCHG*SED(I)
      IF (STKW(I) .LE. STKWMAX)  GO TO 160
      STKW(I)=STKWMAX
      SED(I)=(STKWMAX-EFFSBY*STOREKW)/EFFCHG
  160 GENLOAD=SED(I)+CED(I)+DED(I)
      IF (ABS(GENKW(I)-GENLOAD) .LT. 2.0)  GO TO 210
      ITER=0
C
C      FIND ITERATIVE SOLUTION TO COMP A/C, GENERATOR LOAD, AND
C        ABS A/C BALANCE
C
  170 GENKW(I)=GENLOAD
      IF (ITER.LE.25)  GO TO 180
      IDAY=-1
      RETURN
  180 CALL HEAT(I)
      TONAA=QAABS(I)*COPA/12000.0
      IF (TONAA .LT. TOND(I))  GO TO 190
      QABS(I)=TOND(I)/COPA*12000.0
```

```
      TONA(I)=TONO(I)
      CED(I)=0.0
      GO TO 200
  190 QABS(I)=QAABS(I)
      TONA(I)=TONAA
      TONC(I)=TONO(I)-TONA(I)
      CED(I)=TONC(I)/COPC*3.515
  200 GENLOAD=CED(I)+SED(I)+DED(I)
      IF (ABS(GENKW(I)-GENLOAD) .LT. 2.0)  GO TO 210
      ITER=ITER+1
      GO TO 170
  210 QWSTD(I)=QAABS(I)-QABS(I)+QOILA(I)
      PMFUEL(I)=HRE(I)*GENKW(I)/FV
      BFUEL(I)=QBOIL(I)/(FV*BEFF)
      DBFUEL=DBFUEL+BFUEL(I)
      DPMFUEL=DPMFUEL+PMFUEL(I)
      DTONA=DTONA+TONA(I)
      DTONC=DTONC+TONC(I)
      DCED=DCED+CED(I)
      DGENKW=DGENKW+GENKW(I)
      DTQRCV=DTQRCV+TQRCV(I)
      DQWSTD=DQWSTD+QWSTD(I)
      RETURN
      END
```

```
      BLOCK DATA GENDATA
C
C        BLOCK DATA ROUTINE GENDATA INITIALIZES THE ARRAYS WHICH
C         CONTAIN THE PROPERTIES OF THE VARIOUS GENERATORS
C
      COMMON /SPECS/ PERX(13),WATJY(13),EXY(13),RADY(13),BHPX(13),
     $   BHPY(13),EGY(13),LHVY(13),BHPT(13),RADT(13),EXHT(13),KWLOAD(13)
     $  ,FUCON(13),BNBFC(13),BNBEX(13),BNBWH(13),DFCONY(13),QRCY(13),
     $   LOY(13),BTFCON(13),BTEXHT(13),WAUK(13),WAUKQR(13),WAUKLO(13),
     $   NBFCON(13),NBEXT(13),NBWJ(13),NBLO(13),NBCFC(13),NBCEX(13),
     $   NBCWJ(13),NBCLO(13),FMSFC(13),FMWJ(13),FMEX(13),FMLO(13),
     $   CATSFC(13),CATHG(13),CATLO(13),C315FC(13),C315LO(13),C315EW(13)
     $  ,F968EX(13),F968LO(13),F968WJ(13),F968FC(13),SKW(12)
      REAL KWLOAD,LHVY,LOY,NBCEX,NBCFC,NBCLO,NBCWJ,NBEXT,NBFCON,NBLO,
     $     NPWJ
C
      DATA PERX/0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1.0,1.1,1.2/
      DATA WATJY/0.57,0.47,0.411,0.375,0.355,0.349,0.344,0.34,0.335,
     $           0.33,3*0.32/
      DATA EXY/0.275,0.255,0.244,0.238,0.233,0.230,0.225,6*0.220/
      DATA RADY/0.05,0.068,0.08,0.09,0.098,0.095,3*0.08,0.10,3*0.14/
      DATA BHPX/260.0,300.0,350.0,400.0,450.0,500.0,550.0,600.0,650.0,
     $           700.0,750.0,800.0,0.0/
      DATA BHPY/0.0,0.10,0.175,0.225,0.262,0.29,0.315,0.33,0.335,0.321,
     $           3*0.29/
      DATA EGY/0.0,0.0,0.77,0.805,0.835,0.859,0.876,0.891,0.904,0.914,
     $          0.92,0.92,0.91/
      DATA LHVY/11500.0,11000.0,10350.0,9800.0,9450.0,8975.0,8400.0,
     $   8200.0,8075.0,8000.0,7975.0,7975.0,7975.0/
      DATA BHPT/0.0,0.03,0.07,0.095,0.115,0.13,0.145,0.157,0.179,0.186,
     $   0.186,0.186,0.186/
      DATA RADT/0.48,0.428,0.395,0.37,0.349,0.33,0.315,0.3,0.29,0.28,
     $   0.27,0.27,0.27/
      DATA EXHT/0.47,0.48,0.49,10*0.50/
      DATA KWLOAD/0.0,50.0,100.0,150.0,200.0,250.0,300.0,350.0,5*400.0/
      DATA FUCON/0.0,3.8E6,4.2E6,4.7E6,5.2E6,5.7E6,6.2E6,6.75E6,7.3E6,
     $   7.3E6,7.3E6,7.3E6,7.3E6/
      DATA BNBFC/6*9979.0,9820.0,9720.0,9730.0,9840.0,3*9950.0/
      DATA BNBEX/6*1.23,1.525,1.83,2.155,2.48,3*2.84/
      DATA BNBWH/6*0.592,0.695,0.780,0.87,0.95,3*1.63/
      DATA DFCONY/6*10200.0,10010.0,3*9900.0,3*9950.0/
      DATA QRCY/0.0,0.38,0.75,1.10,1.44,1.70,1.95,2.22,2.47,2.73,3*3.00/
      DATA LOY/0.0,0.17,0.34,0.50,0.63,0.77,0.91,1.04,1.18,1.32,3*1.46/
      DATA BTFCON/0.0,4*40000.0,30500.0,27700.0,25600.0,24100.0,23000.0,
     $   3*22350.0/
      DATA BTEXHT/0.0,8.2,8.3,8.5,8.6,9.05,9.27,9.55,9.95,10.55,3*11.5/
      DATA WAUK/5*11.23,10.97,10.71,10.46,10.33,10.235,3*10.2/
      DATA WAUKQR/5*0.63,0.79,0.95,1.11,1.27,1.44,3*1.60/
      DATA WAUKLO/5*0.07,0.09,0.11,0.13,0.15,0.17,3*0.18/
      DATA NBFCON/5*10300.0,9450.0,9210.0,9070.0,8995.0,8980.0,3*8970.0/
      DATA NBEXT/0.0,0.46,0.76,1.06,1.36,1.67,1.97,2.28,2.6,2.93,3*3.27/
      DATA NBWJ/0.0,0.28,0.55,0.83,1.01,1.2,1.34,1.48,1.64,1.83,3*2.02/
      DATA NBLO/0.0,0.16,0.32,0.48,0.64,0.77,0.98,1.18,1.43,1.74,3*2.04/
```

```
      DATA NBCFC/5*10000.0,9450.0,9200.0,9050.0,8980.0,8960.0,3*8950.0/
      DATA NBCEX/5*3.42,4.2,5.0,5.8,6.6,7.4,3*8.2/
      DATA NBCWJ/5*2.76,3.02,3.40,3.70,4.15,4.60,3*5.08/
      DATA NBCLO/5*1.61,1.94,2.40,2.95,3.60,4.40,3*5.14/
      DATA FMSFC/6*10921.0,10650.0,10375.0,3*10239.0,10375.0,10509.0/
      DATA FMWJ/0.0,0.044,0.089,0.133,0.177,0.220,0.253,0.285,0.320,
     $          0.360,0.400,0.460,0.520/
      DATA FMEX/0.0,0.044,0.089,0.133,0.177,0.220,0.355,0.509,0.625,
     $          0.710,0.810,0.950,1.100/
      DATA FMLO/0.0,0.076,0.156,0.234,0.313,0.390,0.456,0.541,0.608,
     $          0.665,0.720,0.810,0.900/
      DATA CATSFC/6*12500.0,12280.0,11870.0,11540.0,11420.0,3*11400.0/
      DATA CATHG/0.0,0.275,0.55,0.85,1.125,1.425,1.625,1.925,2.2,2.5,
     $              2.7,2.875,3.055/
      DATA CATLO/0.0,0.05,0.1,0.15,0.2,0.225,0.2755,6*0.3/
      DATA C315FC/3*12495.0,12300.0,11950.0,11454.0,7*11107.0/
      DATA C315LO/3*0.43,0.475,0.57,0.66,0.73,0.85,0.94,0.98,3*1.13/
      DATA C315EW/0.,0.25,0.5,0.6,0.95,1.125,1.225,1.4,1.675,1.9,3*2.07/
      DATA F958EX/3*0.57,0.73,0.85,0.97,1.1,1.25,1.4,1.57,3*1.75/
      DATA F958LO/3*0.62,0.67,0.78,0.89,1.09,1.14,1.28,1.45,3*1.6/
      DATA F958WJ/3*0.35,0.38,0.44,0.5,0.57,0.64,0.72,0.815,3*0.91/
      DATA F958FC/3*13593.,12500.,11350.,10738.,10300.,10100.,5*10060./
      DATA GKW/1540.0,425.0,2200.0,1750.0,4415.0,478.0,475.0,500.0,
     $            315.0,358.0,400.0,1200.0/
      END
```